

AN ANALYSIS OF SURFACE WAVES
GENERATED BY A SUBMERGED HYDROFOIL

C. E. JONES, JR.
AND
W. H. BROOKS, JR.
1953

Library
U. S. Naval Postgraduate School
Monterey, California

AN ANALYSIS OF SURFACE WAVES
GENERATED BY A SUBMERGED
HYDROFOIL

By

Cowan E. Jones, Jr.
Lieutenant^U, U.S. Navy

Wharton H. Brooks, Jr.
Lieutenant (Junior Grade), U.S. Navy
B.S., U.S. Naval Academy, 1947

Submitted in partial fulfillment of
the requirements for the degree of

NAVAL ENGINEER

From the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

(1953)

ABSTRACT

TITLE: An Analysis of Surface Waves Generated by a Submerged Hydrofoil.

AUTHORS: Lieutenant Cowan E. Jones, Jr., U. S. Navy
Lieutenant (Junior Grade) Wharton H. Brooks, Jr.,
U. S. Navy

Submitted to the Department of Naval Architecture and Marine Engineering on 25 May 1953 in partial fulfillment of the requirements for the degree of Naval Engineer.

This investigation is a study of the characteristics of the surface wave generated by a submerged hydrofoil.

The experimentation is conducted on essentially a two-dimensional basis. Measurements were taken along the centerline of a circulating water channel. The wave generator is an infinite aspect-ratio foil of NACA 4412 designation. Generated under controlled conditions of hydrofoil angle of attack, depth of submergence, and stream velocity, the wave is defined by measurements of basic dimensions such as amplitude and wave length.

Results obtained are:

1. $\lambda = \frac{2\pi v^2}{g}$ as predicted by theory.
2. Curves expressing the relationship: amplitude versus angle of attack, submergence and velocity.

It is concluded that deep water waves can be simulated in a circulating water channel. An extension of the range of this type of experimentation can lead to a complete solution to the characteristics of surface waves generated by a submerged hydrofoil.

Cambridge, Massachusetts
25 May, 1953

Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

In accordance with the requirements for the degree of
Naval Engineer, we submit herewith a thesis entitled "An
Analysis of Surface Waves Generated by a Submerged Hydro-
foil."

Respectfully,

NOTATION

- a. Wave amplitude.
- C. Chord-length of hydrofoil.
- d₀ Depth of the stream in the flume.
- d₁ Depth of submersion of the hydrofoil,
measured from the surface to the tip of the leading edge.
- Fr. Froude no. of the flume $\frac{V}{\sqrt{gd_0}}$.
- Fr. Froude no. of the hydrofoil $\frac{V}{\sqrt{gc}}$.
- H. Manometer head (feet)
- L. Width of flume.
- Q. Flow rate of the flume (cubic feet/second).
- V. Velocity of flow (feet/second).
- α . Angle of attack of the foil.
- λ . Wave-length.
- l₁ Horizontal distance from the hydrofoil leading edge to the
first wave hollow.
- l₂ Horizontal distance from the hydrofoil leading edge to the
first wave crest.
- y₀ The vertical distance between the undisturbed stream surface
and the first wave hollow.
- y₁ The vertical distance from the undisturbed stream surface
to the peak of the wave formed above the front of the
foil (when occurring).

NOTES

1. Two points.
2. Two points at right angles.
3. Right of the system in the line.
4. Right of connection of the hydraulic system from the surface to the lip of the landing edge.
5. $\frac{V}{g}$ Right no. of the line.
6. $\frac{V}{g}$ Right no. of the hydraulic system.
7. Distance from (left).
8. Right of line.
9. Right no. of the line (under load/weight).
10. Right of line (load/weight).
11. Right of weight of the line.
12. Two points.
13. Horizontal distance from the hydraulic landing edge to the line.
14. Horizontal distance from the hydraulic landing edge to the line.
15. The vertical distance between the horizontal ground surface and the first curve.
16. The vertical distance from the horizontal ground surface to the point of the curve (under load/weight).

TABLE OF CONTENTS

<u>Section</u>	<u>Contents</u>	<u>Page</u>
I	INTRODUCTION	1
II	PROCEDURE	4
III	RESULTS	7
IV	DISCUSSION OF RESULTS	17
V	CONCLUSIONS	22
VI	RECOMMENDATIONS	23
VII	APPENDIX	
	A. Detailed procedure and Description of Equipment.	25
	B. Summary of Data and Calculations.	34
	C. Sample Intermediate Plots.	45
	D. Literature Citations.	46

TABLE OF CONTENTS

Page	Chapter	Section
i	INTRODUCTION	I
4	PROLOGUE	II
7	CHAPTER I	III
17	DISCUSSION ON CHAPTER I	IV
22	CHAPTER II	V
23	PROLOGUE	VI
	APPENDIX	VII
25	1. Detailed procedure and description of experiment.	
26	2. Summary of data and calculations.	
27	3. Sample experimental data.	
28	4. Literature citation.	

I. INTRODUCTION

The use of hydrofoils attached to the hull of a surface vessel is not a new idea. Their application has been attempted in many ways. In the latter part of the last century, Alexander Graham Bell designed a small high-speed craft equipped with foils which attained remarkable speeds for the power then installed. During World War I, the British Admiralty investigated the possibility of using foils on ships with the idea of lifting a ship bodily out of the water to reduce its susceptibility to torpedo attack, but investigations were abandoned without conclusive results.

The Denny-Brown Stabilizer, which was first introduced commercially in the 1920s, represents a successful application of hydrofoils on surface vessels. The stabilizer consists of a hydrofoil located on each side of a vessel's hull at the turn of the bilge. The hydrofoils are actuated by machinery within the ship which causes them to rotate to counteract and reduce the roll of the vessel in a seaway.

For the past fifteen years hydrofoils for use on high-speed surface craft have become increasingly popular. However, their use has been restricted to very small high-speed craft whose displacement is small enough to permit the foils to lift the craft out of the water. With the exception of the Denny-Brown Stabilizers, no real attempt has been made to apply hydrofoils to large ships.

The attachment of hydrofoils to a ship's hull for the purpose

of reducing wave resistance is a comparatively new idea. In a recent paper, read before the 1953 meeting of the Society of Naval Architects and Marine Engineers, Professor M. A. Abkowitz of M.I.T. presented his ideas and the results of his experiments showing the possibility of reducing the wave resistance of ships by the use of hydrofoils located at the forefoot. Under Professor Abkowitz's supervision, towing tank model experiments have been conducted which have shown qualitatively a decrease of model resistance at high speeds.

The objective of this use of hydrofoils is to achieve a net decrease in resistance by accepting increased frictional resistance in return for a large reduction of wave making resistance.

Wave resistance can be considered essentially a pressure phenomenon in which the pressure gradient around a body moving near or on the free surface of a fluid results in the formation of a system of gravity waves. The most prominent, in the case of a surface hull of large displacement, is the bow wave. A reduction in the amplitude of the generated waves by means of a hydrofoil attached to the hull represents a lower energy loss from the moving vessel, which may result in an increase in speed or a reduction in the required horsepower for a proposed design. The presence of a hydrofoil in the vicinity of a vessel's bow, so located that its generated wave system would partially cancel the ship's generated waves (particularly the bow wave), could reduce the wave making resistance of the vessel. Furthermore, as a secondary advantage, this device, by its very location, has the useful characteristic of reducing the pitching of a vessel in a seaway.

[illegible]

Once the type of the hydrofoil has been decided upon, the problem of locating it with respect to the fluid is to achieve optimum wave resistance as littlely prone to itself. It is therefore necessary that the characteristics of a hydrofoil operating near the surface of a fluid be available. The purpose of this investigation is to analyze the behavior of a typical hydrofoil and determine its characteristics. In a literature survey conducted by the authors, it became obvious that information pertaining to hydrofoil characteristics in producing surface waves was not available. Certain work has been done in regard to the analysis of surface waves generated by a few geometrical shapes (principally bodies of revolution) and the general characteristics of surface waves have been theoretically defined. However, no work has been done on hydrofoils. Therefore, it was decided to examine the characteristics of a wave system generated by a particular hydrofoil, operating at various angles of attack, velocities, and depths of submergence.

Attempts to analyze wave generation by hydrofoils previously had been made in the towing tank at M.I.T., but the results indicated that a towing carriage rather than the installed towing-arms would be necessary for extensive study. The best method available appeared to be a two-dimensional analysis in the circulating water channel installed in the Hydrodynamic Laboratory at M.I.T.

The first of these is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The second is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The third is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The fourth is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The fifth is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The sixth is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The seventh is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The eighth is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The ninth is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood. The tenth is the fact that the system is not a simple one. It is a complex one, and it is one that is not easily understood.

II PROCEDURE

The wave profile was obtained by running a centerline traverse the length of the test section. The surface elevation at each point was obtained by the point gage; the horizontal distances were fixed by alignment of the telescope cross hairs on the probe tip and reading of location on the scale affixed to the telescope bench. The location of the probe tip may be measured to 0.01 centimeter with such a point gage, and the telescope location read to .02 inches. The instrumentation, simple as it may seem, is very precise in comparison to the inherent fluctuation in a circulating water channel.

The profile points were taken at intervals consistent with the wave length and amplitude, and the curve fixed by these points was the basic result of each run. Because of the large number of runs necessary, averaging of several readings of surface elevation at each point was not feasible. The averaging was done by eye, and only one reading obtained at each point. To avoid errors in instrument reading, profile points were plotted as they were obtained, and examination of the resulting curves showed that this method gave sufficient precision, (see sample profiles appendix C).

In conducting the runs, velocity (V), angle of attack (α), depth of submergence (d_1) and total depth of flow (d_0) were controllable.

To analyze the resulting wave, three types of flow were considered, 1) approach flow, 2) transition zone, 3) steady state wave formed after transition. Wave length of the steady state portion (λ),

II. Discussion

The wave profile was obtained by running a computer program and length of the last section. The surface elevation at each point was obtained by the point gauge; the horizontal distance was fixed by alignment of the reference cross hairs on the ground and water level of location on the scale attached to the telescope stand. The location of the gauge tip may be measured to 0.01 centimeter with a point gauge, and the distance between gauge to 0.05 inches. The instrumentation, simple as it may seem, is very precise in comparison to the inherent fluctuations in a fluctuating water surface.

The profile points were taken at intervals consistent with the wave length and amplitude, and the curve fitted by means of a least squares method of wave form. Because of the large number of runs necessary, averaging of several readings of surface elevation at each point was not feasible. The averaging was done up to 10, and only one reading obtained at each point. In order to avoid error in the amount of reading, profile points were divided as they were obtained, and estimated of the resulting curve showed that this method gave sufficient precision. Two angles, relative to the wave, in conducting the runs, namely (1) angle of attack (2) angle of observation (3) and (4) angle of flow (5) were maintained. In order to obtain the wave form, three types of flow were obtained: (1) approach flow; (2) transition flow; (3) wave flow were formed from the wave form. The location of the wave form (4) formed from the wave form.

wave amplitude in the steady state region (a), and the characteristic dimensions of the transition region (y_0, y_1, l_1, l_2) comprised the data obtained from evaluation of the profiles.

Three types of run were taken, according to the data desired.

1) Full profile the length of the test section or to the point where instability of flow made measurements doubtful. From such a profile, all variables could be measured.

2) A profile from undisturbed approach flow through the transition zone, and surface elevation only of the steady state flow at maximum and minimum points. This yields all data except wave length and shape of the steady state portion.

3) Measurement of elevation of approach flow and of the maxima and minima in the steady state wave. This gives only amplitude of the steady wave.

Evaluation of Data.

Variables were obtained in the following manner.

Type 1 runs) " λ " and " a " represent an average of all steady state waves obtained in each run. This, plus the averaging implicit in drawing a smooth curve through the plotted points, yielded reasonable, consistent results. For the parameters of the transition region, we have, of course, but one measurement per run. Fortunately, the transition zone, free from wall and side support effects, is highly stable, and profile measurements to the order of accuracy of the approach flow were obtainable.

Type 2 runs) " a " is the difference of the averages of maxima and minima. The transition zone is evaluated as in type 1 runs.

were obtained in the study area (a), and the character-

istic distribution of the sedimentary rocks (b, c, d, e, f, g, h, i, j, k, l, m, n, o, p, q, r, s, t, u, v, w, x, y, z).

These data obtained from examination of the profiles.

These types of the study area, according to the data obtained.

1) The first type of the study area is the study area of the study area.

where a characteristic of the study area is the study area.

profile, all the data obtained from the study area.

2) The second type of the study area is the study area of the study area.

the study area, and the study area of the study area.

the study area and the study area. The study area of the study area.

and the study area of the study area.

3) The third type of the study area is the study area of the study area.

and the study area of the study area. The study area of the study area.

the study area.

the study area.

The study area was obtained in the following manner.

The study area (a) and the study area (b) are the study area.

the study area is the study area. The study area of the study area.

in the study area, the study area of the study area.

the study area of the study area. The study area of the study area.

we have, of course, but one measurement for the study area.

the study area, the study area of the study area.

the study area, and the study area of the study area.

the study area of the study area.

The study area (a) is the study area of the study area.

the study area of the study area. The study area of the study area.

Type 3 runs) "a" only is evaluated and is, as before, the difference of the averages of maxima and minima.

Total 7 items

distance of the system of the system

III RESULTS

1. There is no measurable damping present over the length of the test section or any discernable damping to the point where weir overfall occurs. As high as ten wave-lengths were observed with no apparent change of amplitude or wave-length.

2. It is possible to simulate deep water effects in a circulatory water channel. See Figure XIII.

3. There is no rise of the surface above the foil section at submergences greater than .95 C.

4. There is no effect on approach flow more than one chord-length ahead of the foil.

5. The theoretical relation

$$\lambda = \frac{2 \pi v^2}{g} \quad (1)$$

is confirmed. A plot of this is shown in Figure II.

6. Curves of α/c versus R , at various angles of attack.

7. Curves of α/c versus d_1/c at various Froude numbers and angles of attack.

8. The following numerical averages and range of variations from these averages were found relating the transition zone to the steady wave:

	y_0/a	L_1/λ	L_2/λ
Avg.	.533	.50	1.04
Min.	.44	.46	0.95
Max.	.67	.54	1.14

CHAPTER III

1. There is no considerable change in the length of the test section at any distance from the point where the oscillations occur. It is also to be noted that the wave-lengths are observed with an accuracy of one-tenth of a wave-length.

2. It is possible to observe deep water waves in a ship's wake. The wave-lengths are about 100 ft. and the period is about 10 sec.

3. There is no change in the surface waves of the ocean at distances greater than 100 ft.

4. There is no effect on the surface waves of the ocean of the depth of the water.

5. The theoretical relation

$$(1) \quad \lambda = \frac{2\pi v}{f}$$

is confirmed. A plot of λ versus f is shown in Figure II.

6. Curves of λ versus f at various angles of attack.

7. Curves of λ versus f at various depths of water.

8. Curves of λ versus f at various depths of water.

9. The following numerical averages and range of variations from these averages are given for the quantities λ and f in the

table below:

λ	f	λ	f
1.00	1.00	1.00	1.00
1.05	1.05	1.05	1.05
1.10	1.10	1.10	1.10
1.15	1.15	1.15	1.15
1.20	1.20	1.20	1.20
1.25	1.25	1.25	1.25
1.30	1.30	1.30	1.30
1.35	1.35	1.35	1.35
1.40	1.40	1.40	1.40
1.45	1.45	1.45	1.45
1.50	1.50	1.50	1.50
1.55	1.55	1.55	1.55
1.60	1.60	1.60	1.60
1.65	1.65	1.65	1.65
1.70	1.70	1.70	1.70
1.75	1.75	1.75	1.75
1.80	1.80	1.80	1.80
1.85	1.85	1.85	1.85
1.90	1.90	1.90	1.90
1.95	1.95	1.95	1.95
2.00	2.00	2.00	2.00

VARIATION OF WAVE-LENGTH WITH TOTAL DEPTH OF WATER

$\alpha = 2^\circ$ $d_1 = 1.06C$
M.I.T. 25 MAY 1953
C.E. JONES, JR.
W.H. BROOKS, JR.

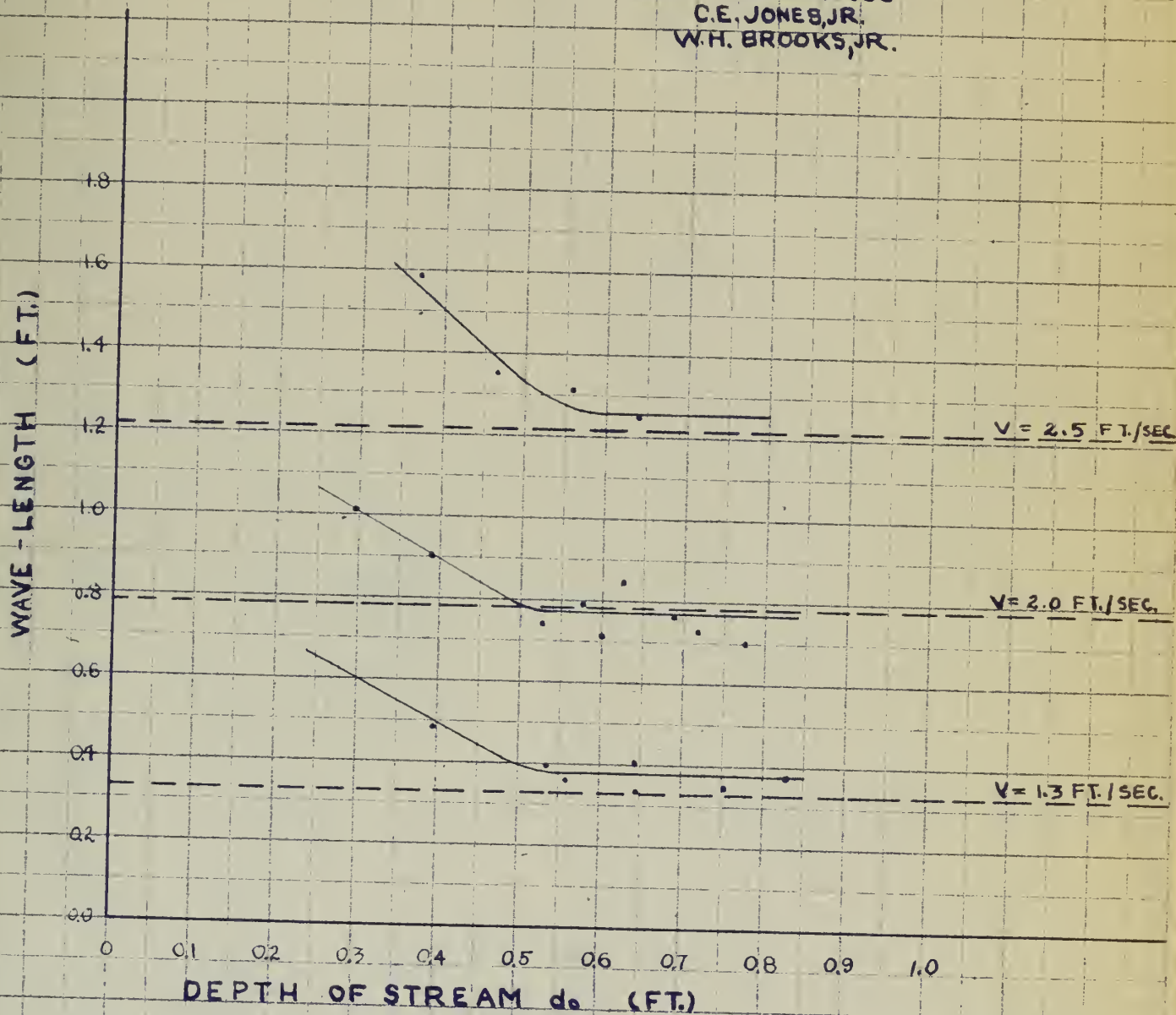
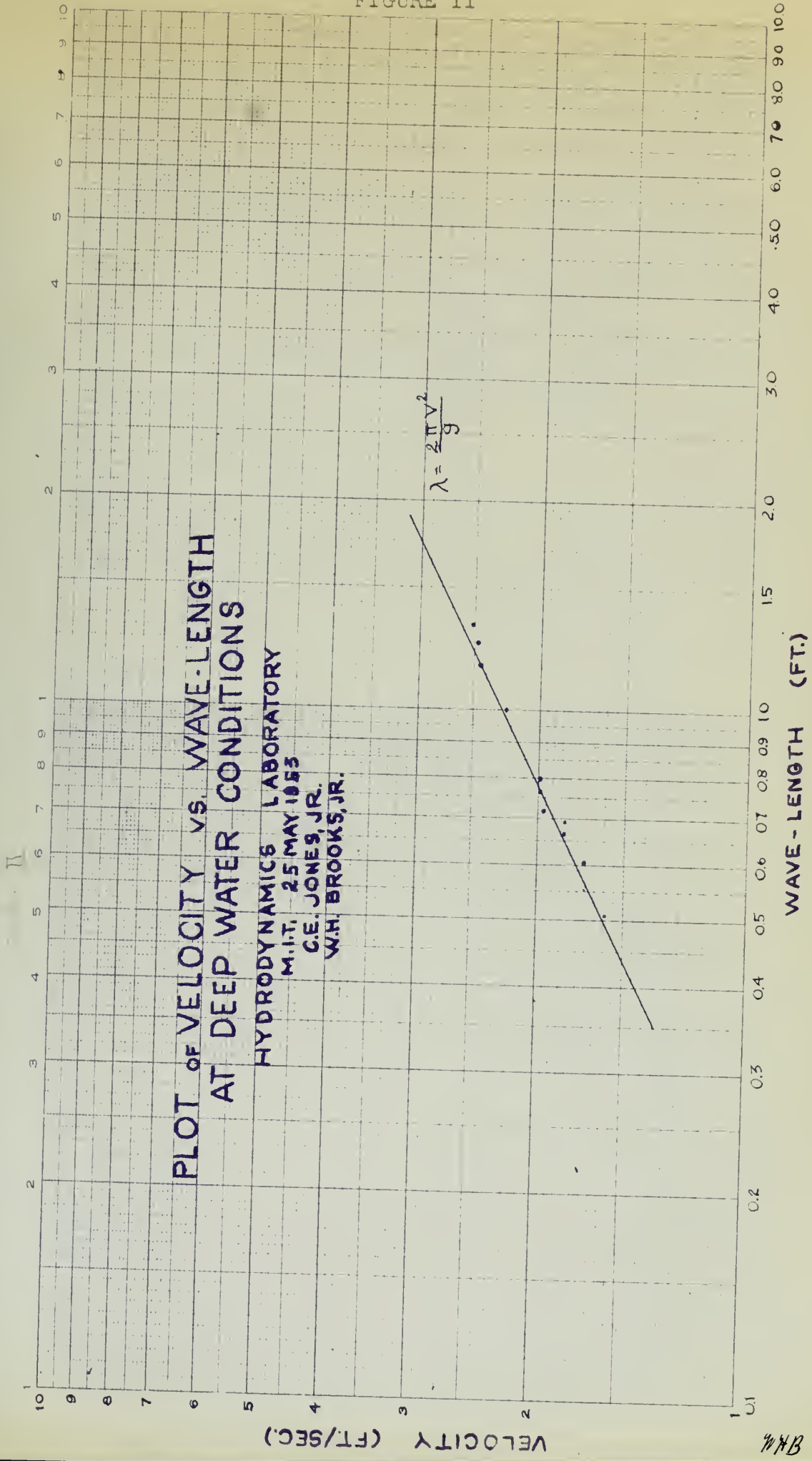
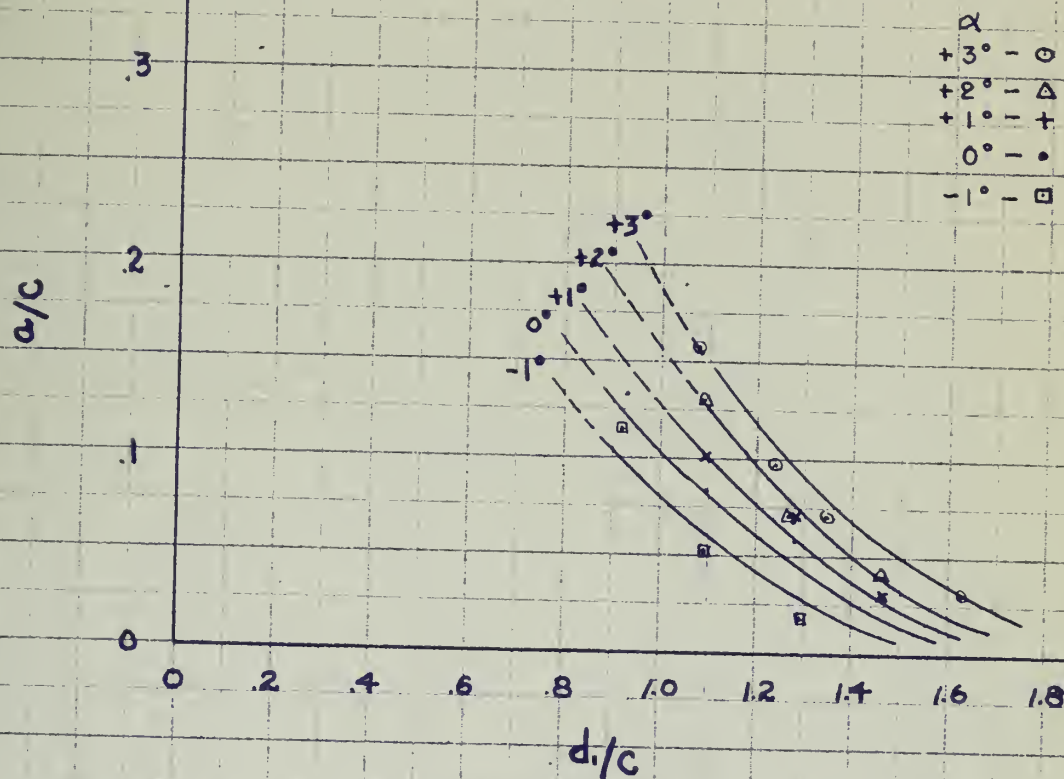


FIGURE II

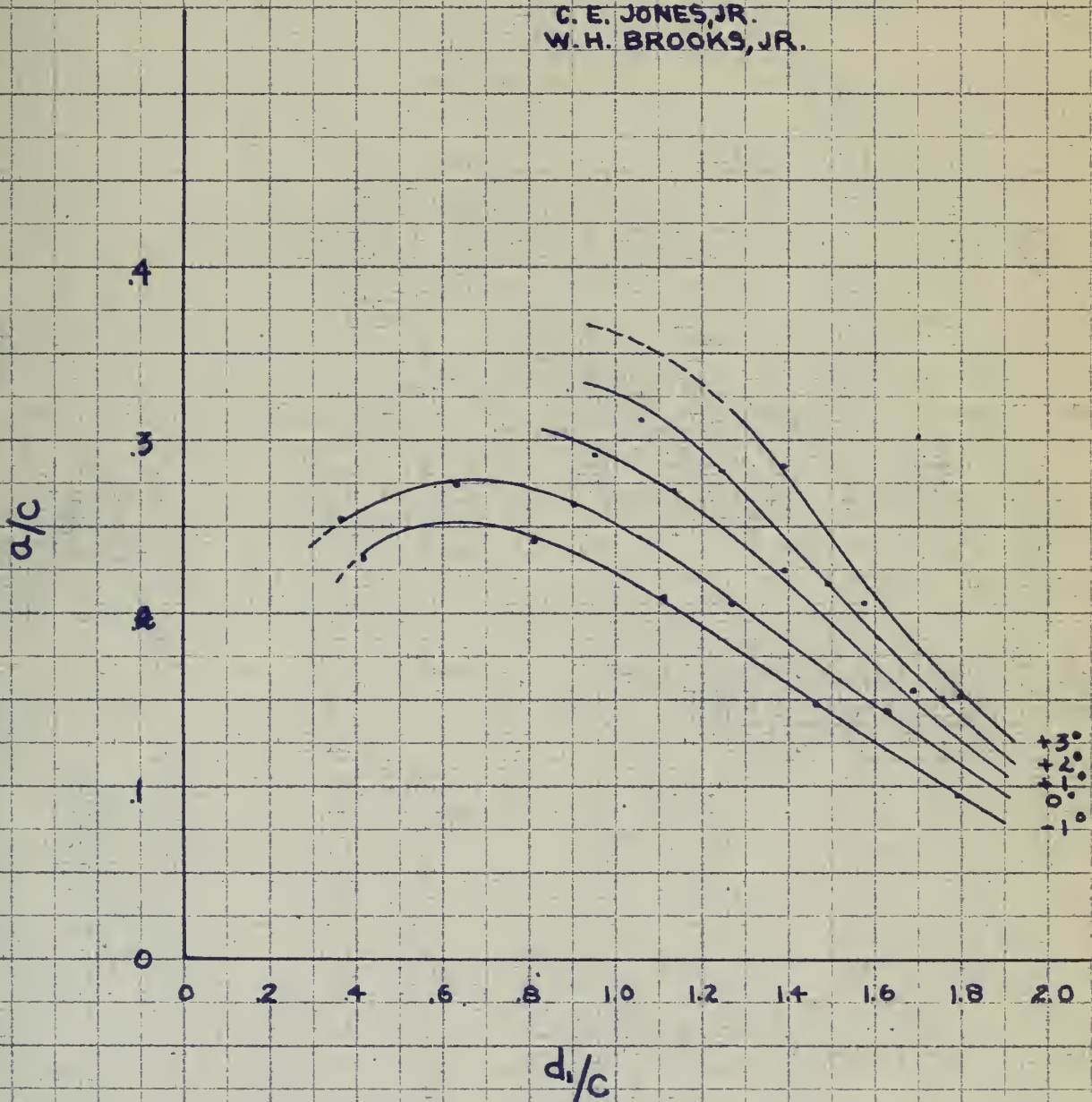


BMA cef

PLOT OF a/c vs. d/c
 AT $Re = .550$
 AT VARIOUS ANGLES OF ATTACK
 C. E. JONES, JR.
 W. H. BROOKS, JR.



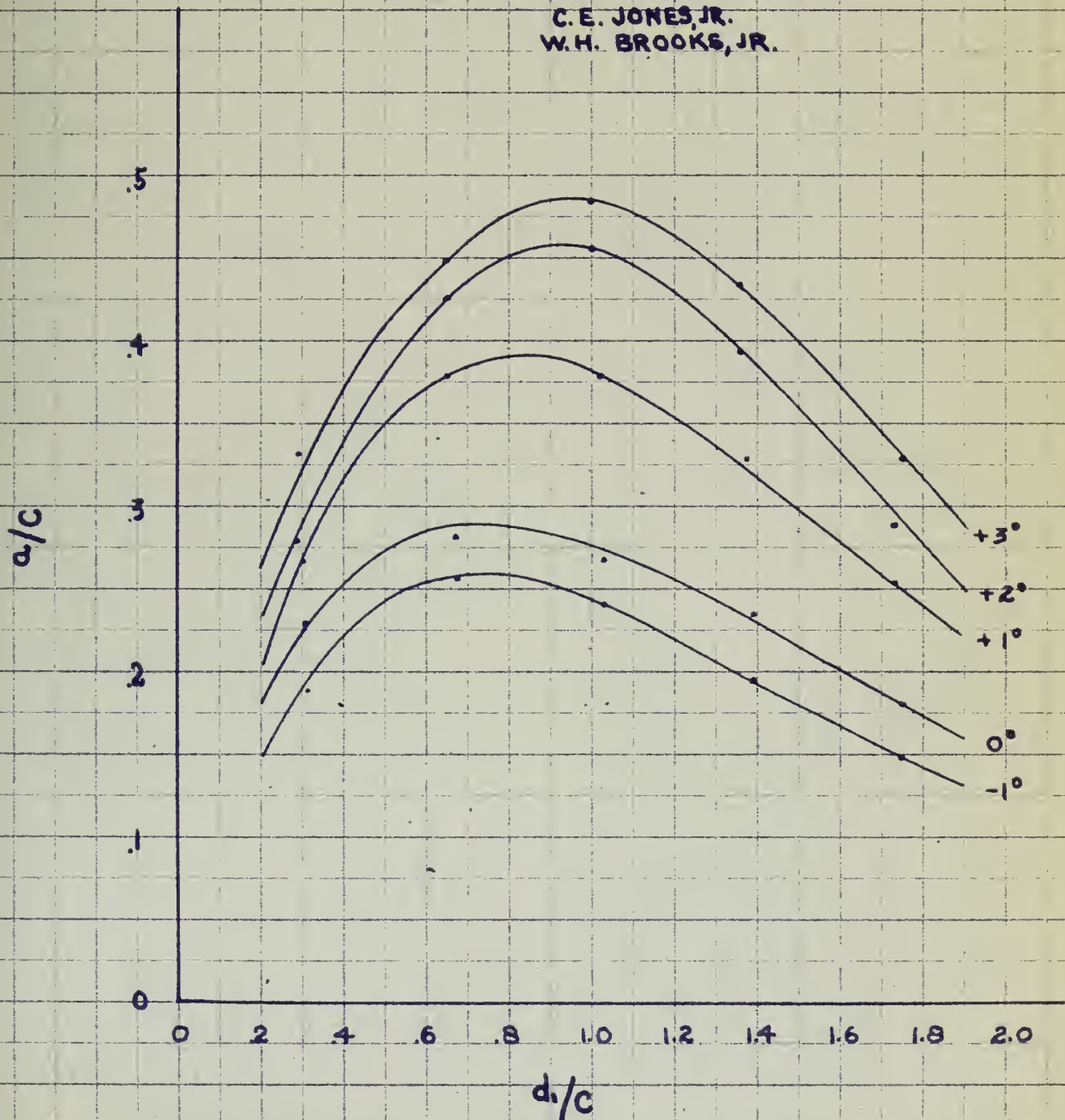
PLOT OF a/c vs. d_1/c
AT $Re = .733$
AT VARIOUS ANGLES OF ATTACK
C. E. JONES, JR.
W. H. BROOKS, JR.



R5 MAY 1953

cej WHB

PLOT OF a/c vs. d_1/c
AT $R_1 = .920$
AT VARIOUS ANGLES OF ATTACK
C.E. JONES, JR.
W.H. BROOKS, JR.

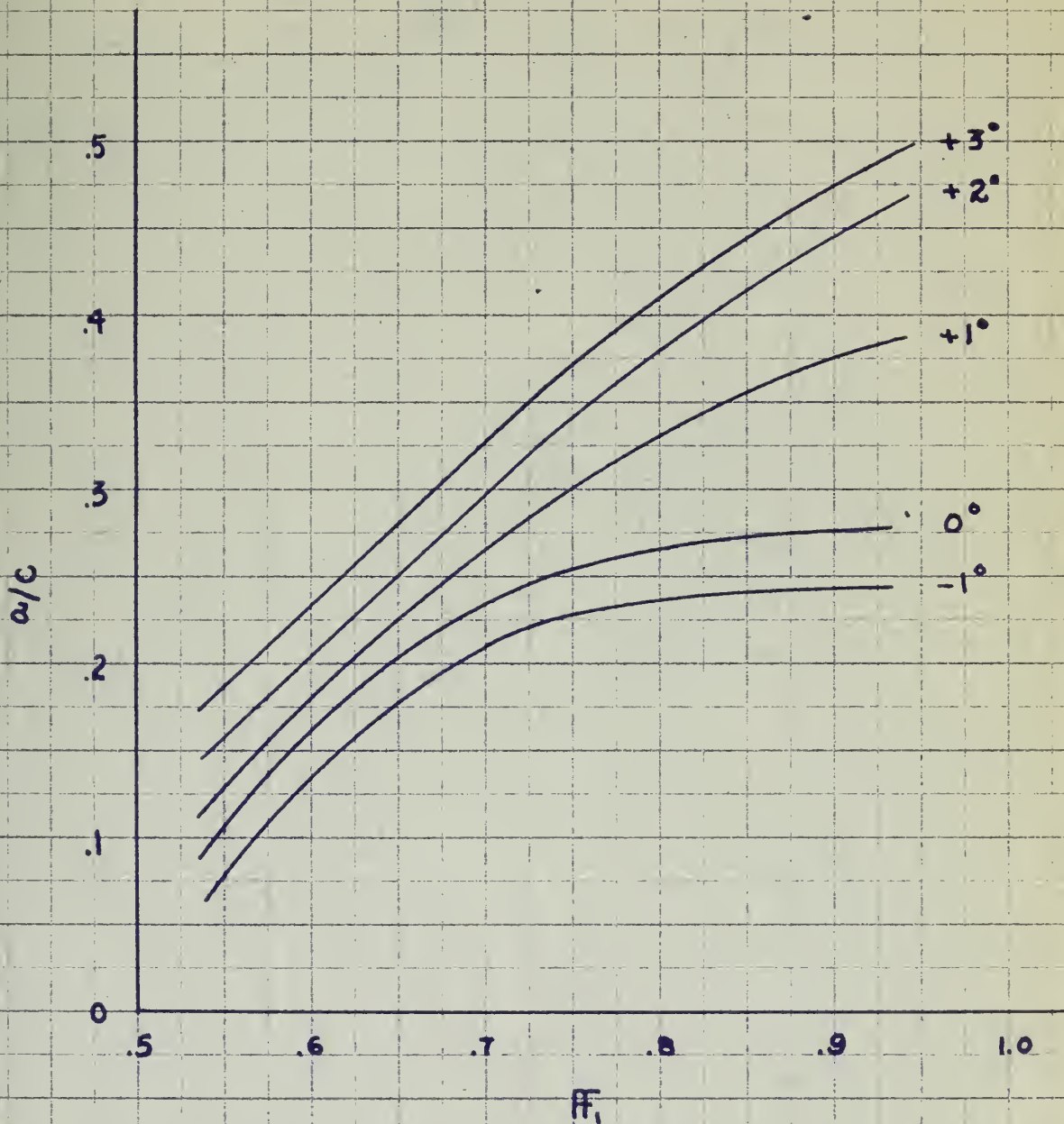


25 MAY 1953

CEJ

W/HB

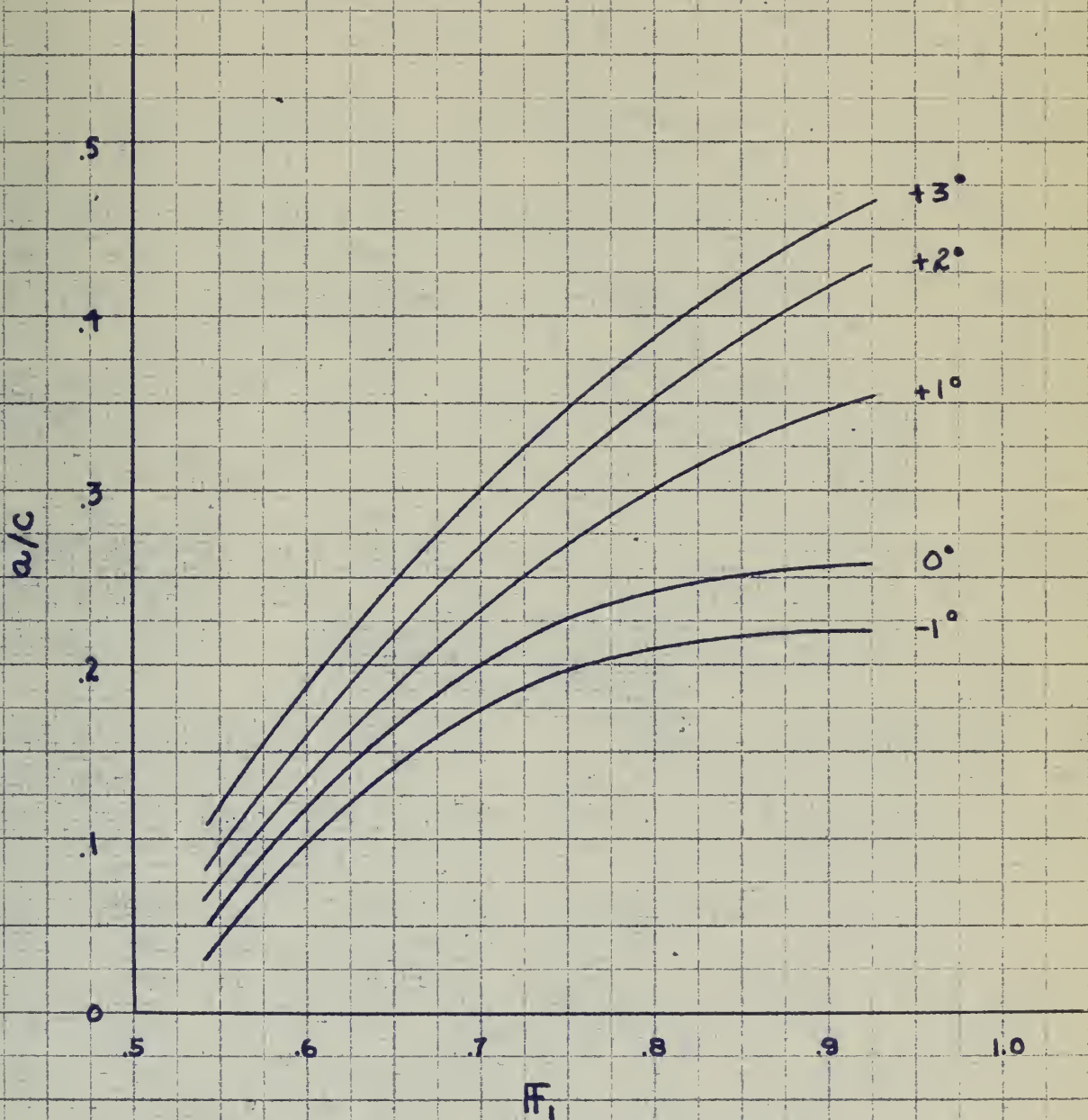
PLOT OF α/c VS F_1
AT A DEPTH OF SUBMERGENCE
OF 1.0 C
AT VARIOUS ANGLES OF ATTACK
C.E. JONES, JR.
W.H. BROOKS, JR.



25 MAY 1953

CEJ WNB

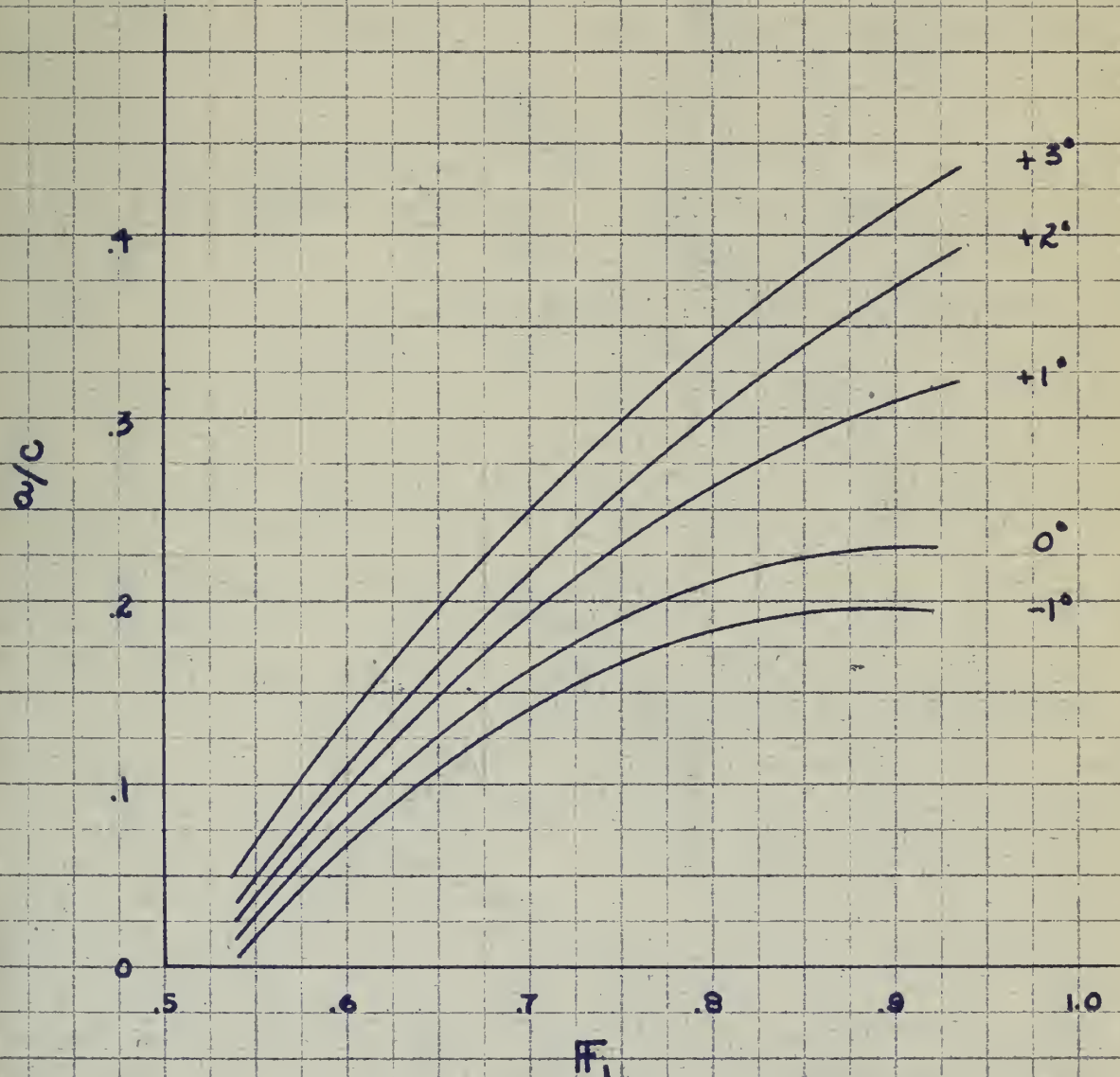
PLOT OF a/c vs. F_1
AT A DEPTH OF SUBMERGENCE
OF 1.2 C
AT VARIOUS ANGLES OF ATTACK
C. E. JONES, JR.
W. H. BROOKS, JR.



25 MAY 1953

CEJ WNB

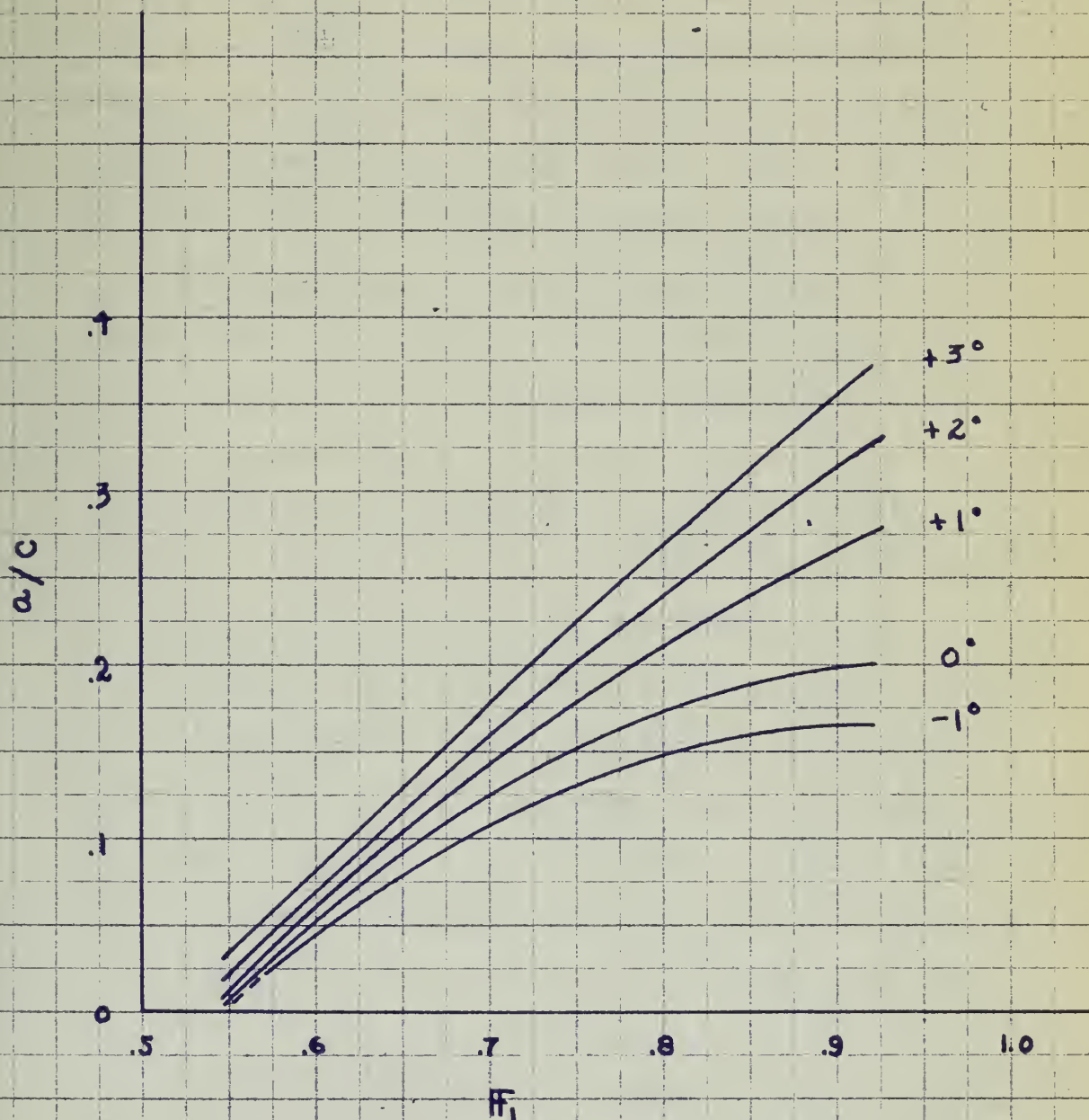
PLOT OF α/c VS. F_1
AT A DEPTH OF SUBMERGENCE
OF 1.4 C
AT VARIOUS ANGLES OF ATTACK
C. E. JONES, JR.
W. H. BROOKS, JR.



25 MAY 1963

CEJ WAB

PLOT OF a/c VS. F_1
AT A DEPTH OF SUBMERGENCE
OF 1.6 C
AT VARIOUS ANGLES OF ATTACK
C.E. JONES, JR.
W.H. BROOKS, JR.



25 MAY 1963

CEJ WNB

IV DISCUSSION OF RESULTS

The object of this research was to find the change in the resulting wave pattern with changes in the conditions of the wave generating hydrofoil. In many cases, the relations were clearly defined and these have been expressed in the preceding section. In other instances (the parameters of the transition zone in particular), where such variations were not clearly defined, interpretation was needed. In these cases, we have made our interpretation and drawn our conclusions. For those who do not agree, the table, Summary of Data, found in appendix B, must comprise the results. It is hoped that sufficient information is expressed therein to aid the research of those individuals interested in hydrofoils.

Since this work was attempted with a view toward the use of hydrofoils in suppression of the wave train of a surface ship, it will be evaluated and interpreted primarily on this basis.

Not previously mentioned in this paper are the serious limitations imposed by the equipment which was used. Principal among them was an overall limitation on range of both velocity and total depth. At the present time, hydrofoils used as wave suppressors have been of chord-length equal to or greater than the draft of the ship model tested. This would mean, in full scale terms, that a destroyer type vessel, operating at a speed of about thirty knots, and using a foil with chord-length of about fifteen feet would give a Froude number on the foil (V/\sqrt{gc}) of about 2.3.

Since this work was attempted with a view toward the use of hydrostatics in the construction of the water main of a certain city, it will be considered and interpreted primarily on this basis.

Not previously mentioned in this paper are the various limits of stress imposed by the equipment which was used. Hydrostatic stress was not an overall limitation on range of stress although the limits of the equipment used in the present study, particularly that of the water main, were based on the limits of the equipment used in the present study. This would mean, in this case, that a hydrostatic stress, operating at a stress of about 1000 psi, and using a wall of 1000 psi, would be a stress of about 1000 psi.

For a typical merchant vessel with a speed of about twenty knots, using a chord-length of twenty feet, the hydrofoil's Froude number might be 1.3. In our test range, the maximum Froude number attained for the foil was 0.92.

This means that the range of experimentation may not allow direct scaling of the results of these tests to a full size ship. This limit was recognized early in the preliminary analysis, and the use of three sizes of foils of about one, two, and three inches was planned. Manufacturing difficulties prevented the use of more than one foil. It is to be noted that the original proposal would have extended the range of Froude number to a value of 1.7. The extension of the range of Froude numbers tested is recommended in order that the scaling methods of ship model testing may be directly applied.

The use of a range of sizes of foils would also have permitted examination of one more variable, chord-length, and would have allowed a check on the validity of the use of Froude number for a body which does not penetrate the surface. Only limited work has been done on this aspect, but it appears that this is the valid scale factor within the limiting assumptions accepted in ship model testing.

Unfortunately, this work makes no contribution to the problem of determining the shape of surface waves. Attempted analysis of wave shape by numerical methods⁽³⁾ proved unsuccessful. Thus, within the frame of characteristic dimensions presented here, the investigator or ship designer must choose which of the many pro-

posed theories he desires to use to express the shape of the wave.

No exact correlation of the characteristic dimensions of the transition was found. Examination of these dimensions indicates that their primary relation is to the respective dimensions of the steady state wave. In other words, ℓ_1 and ℓ_2 are increased by any change which increases λ , and y_0 is increased similarly with increases in "a". In the absence of any better correlation, numerical averages and the range of values obtained are presented. It should be noted that, for waves in which there was breaking of the crest of the first wave, the measured values of neither ℓ_2 or of "a" were usable in this analysis. This is easily explained; the breaker is a region of high energy dissipation which affects the energy content of the wave which follows the breaker. Also of interest may be the fact that the presence of a breaker tends to stabilize the wave which follows, and very good measurements of λ are possible.

During the observation of the hydro-dynamic behavior of the hydrofoil two important phenomena are noteworthy of mention. First, it was noted that within the velocity range of the investigation there was no perceptible influence on the upstream flow in front of the leading edge of the hydrofoil at distances greater than one chord-length. Second, it was noted that at shallow depths of submergence (d_1) a wave hump appeared above the leading edge of the hydrofoil. These two

These figures are given to show the range of the
wave.
The other conditions of the characteristic dimensions of
the radiation are given. The radiation of these elements in
those cases where the radiation is in the region of the
radiation of the elements is given. In other words, λ and λ_0
are indicated by the wave which is indicated by λ and λ_0 in
the radiation of the elements is given. In the region of
the radiation of the elements is given. It would be noted that the
values obtained are given. It would be noted that the
values in which there are indicated in the region of the radiation
wave, the values of the radiation of the elements is given. In
this region, the values of the radiation of the elements is
a region of the radiation of the elements is given. The values
of the radiation of the elements is given. The values of the
radiation of the elements is given. The values of the radiation
of the elements is given. The values of the radiation of the
elements is given. The values of the radiation of the elements
is given. The values of the radiation of the elements is given.

During the investigation of the characteristic dimensions of
the radiation of the elements is given. The values of the
radiation of the elements is given. The values of the radiation
of the elements is given. The values of the radiation of the
elements is given. The values of the radiation of the elements
is given. The values of the radiation of the elements is given.
The values of the radiation of the elements is given. The values
of the radiation of the elements is given. The values of the
radiation of the elements is given. The values of the radiation
of the elements is given. The values of the radiation of the
elements is given. The values of the radiation of the elements
is given. The values of the radiation of the elements is given.

phenomena are of importance to the ship designer if hydrofoils are to be used to reduce the wave making of a ship. The usefulness of the first phenomena is obvious in that the designer can rely on a free uninterrupted flow up a distance of one chord-length in front of the hydrofoil. The second phenomena, characterized by the dimension y_1 , is not clearly defined at the present time. Only one conclusion is drawn--namely that in no case does a hump appear until the depth of submergency (d_1) decreases below .95C. This fact is useful to the designer in that within the Froude number range of this investigation it indicates that the designer should not locate a hydrofoil at the bow of a ship closer than one chord-length to the surface. Otherwise the presence of the hump will tend to offset the wave reducing feature of the hydrofoil.

The results of this investigation show that not only can a flume be used to study the behavior of a hydrofoil in deep water but also that the shallow water effect can easily be discerned by noting variation in wave-lengths with stream depth at various stream velocities. The resulting curves showing this phenomena need no further amplification.

Fortunately, theory and previous experimental work are available with respect to wave length of a surface wave. That the accepted criteria of λ for waves travelling over the surface of a deep body of water was met in the experimental results is a verification of the proposition that deep water conditions can be simulated in a relatively shallow, circulating water channel.

phenomena are of importance to the ship designer. It is
not to be used to reduce the wave loading on a ship. The use-
fulness of the first phenomenon is shown in that the designer
can rely on a free undisturbed flow up to a distance of one ship-
length in front of the hydrofoil. The second phenomenon, however,
is not clearly defined at the present
time. Only one conclusion is drawn—namely that in no case does
a sharp square, with the depth of submergence (d) decreases below
1.75c. This limit is useful to the designer in that within the
range number range of 1.75c investigated it indicates that the
designer should not locate a hydrofoil at the bow of a ship closer
than one ship-length to the surface. Otherwise the presence of
the ship will tend to alter the wave loading factors of the
hydrofoil.

The results of this investigation show that not only can a
flow be used to study the behavior of a hydrofoil in deep water
but also that the surface waves which are easily be disturbed by
smaller vessels in near-surface with almost depth of surface
stream velocity. The resulting waves showing this phenomenon must
be further explained.

Unfortunately, theory and previous experimental work are avail-
able with respect to wave height of a surface wave. The wave
height criteria of λ for waves travelling over the surface
of a deep body of water was not in the experimental results in
a realization of the proposition that deep water conditions can
be simulated on a relatively shallow, circulating water channel.

Since the generated waves are prone to be more unstable in horizontal location than in amplitude, an appreciable spread of experimental points about the mean line resulted.

With reference to wave stability, α/λ greater than 0.085 could not be achieved because of the breaking of the first wave crest. Following this stabilizing breaker α/λ values as high as 0.092 were achieved.

The relation of amplitude to submergence and angle of attack of the hydrofoil represents the primary result of this investigation. In the absence of comparative theory, the curves picturing this variation must be taken at the value indicated by the small deviations from the mean curves. These are design curves, and in addition lead to the following conclusion: for any angle of attack, there is an optimum depth which will produce the greatest amplitude of generated wave. This depth, in itself, is a function of the angle of attack, increasing with increased angle of attack in the manner shown by the curves of a/c vs. d_1/c at the various angles of attack.

This same information, plotted as a/c vs F_1 , is presented, since this form may well be more useful in design.

[illegible]

V CONCLUSIONS

1. This range of experimentation may not allow the results of these tests to be scaled directly to a full sized ship.
2. No clearly defined relationships for the transition region were found.
3. Bow hydrofoils should not be installed at depths of submergence of less than about one chord-length.

Y. LAMINATION

1. This range of lamination may not allow the results of these tests to be applied directly to a field study.
2. No directly related relationship for the lamination region were found.
3. The lamination should not be limited to depths of 100-200 ft. below the surface and depth.

VI RECOMMENDATIONS

1. Extension of the range of F_1 by similar tests to a value of approximately 2.5.

2. The use of geometrically similar foils of a different size to examine the variable, chord-length, and to check the validity of Froude Number as a scale factor.

Experimental Recommendations:

From observations and difficulties experienced, these recommendations are made for refinement of experimental techniques.

1. Insert false side walls in the flume to extend the velocity range and the depth of the flow. This would permit a better attachment of the hydrofoil to the sides and thus eliminate any "strut effect" which is set up by the side supports of the foil.

2. Install a fully adjustable weir gate to permit more precise control of velocity.

3. A more precise method for establishing angle of attack should be used. The present method, with the equipment used in this investigation, requires that the hydrofoil assembly be removed each time and set for a different angle of attack when so desired.

VI. DISCUSSION

1. Extension of the range of V_1 by similar cases of a value of approximately 2.2.
2. The use of potentially similar flows of a different size to examine the variables, characteristics, and to check the validity of results obtained at a single factor.
- Experimental Recommendations:
From observations and difficulties experienced, these recommendations are made for refinement of experimental technique.
 1. Invertible side walls in the flow to extend the velocity range and the width of the flow. This would provide a better estimate of the hydrodynamic to the sides and some assistance in "stiff" effect" which is set up by the side supports of the flow.
 2. Install a fully adjustable side wall to permit more precise control of velocity.
 3. A more precise method for determining scale of attack should be used. The present method, with the adjustment used in this investigation, requires that the specimen be removed each time and set for a different scale of attack when so desired.

VII APPENDIX

CHAPTER IV

The first of the two main divisions of the subject is the history of the art of painting. The second is the history of the art of sculpture. The history of the art of painting is divided into three periods: the ancient, the middle, and the modern. The history of the art of sculpture is divided into two periods: the ancient and the modern. The ancient history of the art of painting is divided into three periods: the Egyptian, the Greek, and the Roman. The ancient history of the art of sculpture is divided into two periods: the Egyptian and the Greek. The middle history of the art of painting is divided into two periods: the Byzantine and the Italian. The middle history of the art of sculpture is divided into two periods: the Byzantine and the Italian. The modern history of the art of painting is divided into two periods: the French and the English. The modern history of the art of sculpture is divided into two periods: the French and the English. The history of the art of painting is divided into three periods: the ancient, the middle, and the modern. The history of the art of sculpture is divided into two periods: the ancient and the modern. The ancient history of the art of painting is divided into three periods: the Egyptian, the Greek, and the Roman. The ancient history of the art of sculpture is divided into two periods: the Egyptian and the Greek. The middle history of the art of painting is divided into two periods: the Byzantine and the Italian. The middle history of the art of sculpture is divided into two periods: the Byzantine and the Italian. The modern history of the art of painting is divided into two periods: the French and the English. The modern history of the art of sculpture is divided into two periods: the French and the English.

APPENDIX A
DETAIL PROCEDURE AND
DESCRIPTION OF EQUIPMENT

DETAILED PROCEDURE

Preliminary Analysis:

The closest approach to a theory for this problem is the work of Lamb⁽⁴⁾ on surface waves due to a moving pressure disturbance.

Though this theory was advanced considering a pressure disturbance at the surface, it was felt that the general method of attack is applicable to disturbances caused by a submerged body. In brief, the theory predicted (a) change of surface elevation over the finite length of the disturbance with the shape of the elevation closely linked to the nature of the disturbance, (b) a transition region of approximately $\frac{1}{2}$ a wave length whose nature was exponential, (c) a damped oscillatory wave. Further, Lord Kelvin had theorized and experimentally checked the fact that no stable wave pattern would result at velocities of less than about 23 cm/sec.⁽⁵⁾

With this background, the method of procedure as stated on page 4 was adopted.

Also apparent in the preliminary analysis was the question of simulating deep water conditions in a channel of this type.

Only this far could theory help; it was necessary to know the general nature of the waves before proceeding.

Sequence of Investigation :

In order to get consistent results, reasonably steady approach flow to the foil had to be achieved. It was considered that this could be accomplished without modification to the channel, as installed, by placing our foil and observation section a distance of about fourteen feet from the inlet. Upon establishing flow with the sluice gate removed from the inlet, it was found that a standing wave existed the entire length of the channel. This difficulty was resolved by lowering the

Preliminary analysis:

The closest approach to a theory for this problem is the work of Lamb⁽¹⁾ on surface waves due to a moving pressure disturbance. Though this theory was advanced considering a pressure disturbance at the surface, it was felt that the general method of attack is applicable to disturbances caused by a submerged body. In brief, the theory predicts (a) change of surface elevation over the finite length of the disturbance with the shape of the elevation closely linked to the nature of the disturbance, (b) a transition region of approximately $\frac{1}{2}$ a wave length where nature was exponential, (c) a damped oscillatory wave. Further, Lamb's theory has been checked and experimentally checked the fact that the results were obtained within the limit at velocities of less than about 50 m/sec. (2)

With this background, the method of procedure as stated on page 4 was adopted.

Also apparent in the preliminary analysis was the question of stimulating deep water conditions in a channel of this type. Only this far could theory help; it was necessary to have the general nature of the waves before proceeding.

Sequence of investigation:

In order to get consistent results, reasonably steady approach flow to the fall had to be achieved. It was considered that this could be accomplished without modification to the channel, as indicated by placing one fall and observation section a distance of about fourteen feet from the inlet. Upon establishing flow with the sluice gate removed from the fall, it was found that a standing wave existed the entire length of the channel. This difficulty was removed by lowering the

sluice gate to create a small head (one to two inches above the level of surface flow) in the inlet tank. This slight contraction of the inlet removed the standing wave, and the length of approach flow was sufficient to take care of the additional surface disturbance caused by the sluice gate.

With satisfactory approach flow established, the foil was placed in the flow; and velocity, submergence and angle of attack were varied to note qualitative effects. Two results were immediately noted: 1) The damping of the wave train was not discernable to the eye; 2) Lord Kelvin's prediction as to minimum velocity was optimistic in terms of stability of this equipment. Only random disturbance was present below a velocity of 1.25 feet per second, and, up to velocities of about 1.4 feet per second, measurement would be difficult.

It was also observed that the foil supports were creating some surface disturbance, and that this disturbance converged at the center of the channel at approximately the second wave crest, independent of the velocity of flow. To the eye, these effects appeared sizable, so it was decided to round the corners of the side supports, and if this did not suffice, to measure the surface profile generated by the supports alone, and try to subtract these values out of the profiles generated by the hydrofoil.

The rounding of the edges of the support pieces produced no change in the size of these disturbances, but, when the supports alone were placed in the flow, there was little or no effect on the surface, and no measurable wave was caused by these supports. Thus, it was decided that the unwanted surface disturbance was being caused, not by the side supports themselves, but by the complex intersection of foil,

...the rate of travel is small (one to two inches over the level
of surface flow) in the lower part. This slight contraction of the
level means the velocity is small, and the length of approach flow is
sufficient to take care of the additional surface resistance caused
by the slight rise.

...When surface flow is established, the flow is laminar
in the first and velocity, and resistance are small at each end of the
to note qualitative effects. The results were (approximately) as follows:
The change of velocity was not appreciable in the first 10 feet
behind the position where the surface velocity was zero in the case of
stability of this equipment. Only minor differences were present be-
hind a velocity of 100 feet per second, and up to velocities of about
100 feet per second, measured would be difficult.

...It was also observed that the flow velocity was constant over the
large distances, and that the distance between the center of
the channel at approximately the same level was small, independent of the
velocity of flow. In the case where surface velocity was small, as it
was found to be in the case of the flow, and it was also
not noticed, the surface profile provided by the velocity
alone, and the surface profile was not at the surface of the channel
by the velocity.

...The position of the edge of the report seems to depend on the
in the case of water discharge, but, when the surface flow was
placed in the flow, there was little or no effect on the surface, and
no noticeable rise was found in the surface. Thus, it was the
which gave the surface profile and the surface profile was not by
the side surface of the channel, but by the surface of the channel by the
the flow, it was found that the surface of the channel was not by the
the surface of the channel.

wall, and support. This was confirmed by observation that side effect first appeared at the surface at a different horizontal location as depth of the foil was changed (moving downstream, as submergence was increased).

As this could not be eliminated without major changes in the mounting, and it was felt that foil and channel wall alone would produce considerable effect even if the supports were removed from the flow, this three dimensional effect remained throughout the experimentation. However, as plotting of the profiles progressed, it was shown that this effect, though tending to make measurement difficult in the vicinity of the second crest, could be averaged out by careful use of the depth gage. Even with very closely spaced profile points, no appearance of this disturbance could be noted on the plotted profiles at the point where visual observation showed that side effects were present in the centerline profile.

A much more harmful effect of this side effect was its contribution to wave instability, particularly at low velocities, and, if a mounting could be designed to eliminate or reduce these disturbances, a minimum velocity much closer to that predicted by Lord Kelvin might be achieved.

Since this investigation would have been of little value unless it could be related to hydrofoil performance in deep water, it was felt that the first objective must be to determine the effects of the comparatively shallow channel. This was done as follows:

At each of several selected velocities, the controllable variables (angle of attack, depth of submergence, and velocity) were held constant while total depth was varied from the maximum allowed by pump

will, not support. This was confirmed by observation that the
two lines appeared at the surface of a shallow horizontal
as depth of the foil was changed (moving downwards, an adjustment
was necessary).

The foil would not be illuminated without being changed in the
morning, and it was left that day and changed with about two
days' intervals until even if the supports were removed from the
lines, the lines themselves would not be illuminated. The experi-
menter, however, as a matter of the physical properties, it was
found that this effect, which seemed to be a result of the
in the vicinity of the second wall, could be removed out by care-
ful use of the upper plate. Even with very closely spaced profiles
before, as a specimen of this observation could be noted on the high-
red profiles at the point where the vertical separation occurs that the
effects were present in the vertical profiles.

A main cause which affected the foil was the distance
from the vertical profiles, particularly at low voltages, and it is
interesting to be observed in relation to the above observations,
A vertical velocity was found to have been observed in that which might
be observed.

Since this investigation would have been of little value unless
it could be related to physical phenomena in deep water, it was
felt that the first objective was to be determined the effects of the
comparatively small amount. This was done as follows:
At each of several selected intervals of the experimental procedure
(range of attack, depth of submergence, and velocity) were held con-
stant while total depth was varied from one extreme to the other by means

capacity to the minimum where total depth was only slightly greater than the depth of submergence. Resulting changes in the characteristics of the generated wave were then the "shallow water effects".

Once the point at which changes occurred was established, investigation proceeded at depths greater than this critical depth and thus deep water runs were simulated.

In addition, the first part of the investigation yielded enough data free of shallow water effects that it was possible to establish the fact that wave length was a function of velocity only.

The remainder of the investigation comprised the collection of sufficient data to establish the effects of α , d_1 , and V on the transition zone and on amplitude of the steady wave.

The results of the investigation confirmed the collection of
 reliable data to establish the effects of α , β , and γ on the
 time gap and on amplitude of the single wave.
 In addition, the first part of the investigation yielded enough
 data that of similar order effects that it was possible to establish
 the fact that wave length was a function of velocity only.
 The results of the investigation confirmed the collection of
 reliable data to establish the effects of α , β , and γ on the wave-
 length gap and on amplitude of the single wave.

DESCRIPTION OF EQUIPMENT

THE HYDROFOIL

The hydrofoil selected for this experiment was the N.A.C.A. 4412 airfoil section. The profile of this section is shown in the appendix Table no. I with a tabulation of its coordinates. The choice of this particular profile was based primarily on the availability of existing data of a similar nature which would be useful in the course of this investigation.⁽¹⁾⁽²⁾ This airfoil is 2.8" in chord length and 18" in wing length. It has a 12 percent thickness ratio with a 4 percent camber. The trailing edge was rounded off slightly to facilitate the machining of the foil. The foil was made of dural and was manufactured by a special milling machine in the Sloan Laboratory of the Institute.

THE WATER CHANNEL

A photograph of the water channel is shown in Figure X. This flume is capable of a maximum flow rate of 1200 G.P.M. It is 18" in width and 24 feet in length. The entrance of the channel contained radiator baffling followed by a converging section to stabilize the channel flow rate and produce as little surface disturbance as possible. For the low velocities needed for this investigation (about 1-2 F.P.S.) this arrangement was not quite satisfactory because standing waves were generated on the upstream side of the test section. A satisfactory flow surface was produced by merely lowering the sluice gate until it made contact with the water surface. Surface disturbance variation, (unsteady) was,

DESCRIPTION OF THE PLANT

THE PLANT

The plant is a small tree or large shrub, 1-2 m. tall, with a single stem. The leaves are alternate, ovate, 5-10 cm. long, 2-4 cm. wide, with a serrated margin. The flowers are small, white, and fragrant. The fruit is a small, round, red berry. The plant is native to the tropics and is found in the lowland forests of the Amazon basin. It is a member of the family *Malvaceae*. The plant is used for its wood, which is hard and durable, and for its bark, which is used for medicinal purposes. The leaves are also used for medicinal purposes. The plant is a member of the genus *Albizia*.

THE BARK

A photograph of the bark of the plant is shown in Figure 1. The bark is smooth and light brown in color. It is composed of a thin outer layer and a thicker inner layer. The outer layer is composed of a thin layer of cork and a thicker layer of bark. The inner layer is composed of a thin layer of wood and a thicker layer of bark. The bark is used for medicinal purposes. The bark is used for the treatment of various diseases, including malaria, fever, and headache. The bark is also used for the treatment of skin diseases. The bark is a member of the genus *Albizia*.

at the most, about $1\frac{1}{2}$ millimeters.

The flow rate of the channel was established by means of a calibrated orifice section located in the piping on the discharge side of the pump. A differential mercury manometer was attached to this section and the flow rate could be obtained by measuring the difference in mercury levels. Then applying the calibration formula

$$Q = 1.806 \sqrt{H} \quad (2)$$

the flow rate and hence the velocity could be determined.

THE MEASURING EQUIPMENT

A depth probe, calibrated in centimeters, was used to measure the heights of the generated waves, the undisturbed stream surface and to establish the vertical height of the foil tip. The probe was mounted on a carriage which could be moved on rails located on top of the flume.

A telescope apparatus shown in Fig. XI was used in measuring the horizontal distances. Due to the long arm on the depth probe, inaccurate horizontal distance readings would result if horizontal distances were measured using the probe carriage. The telescope was mounted on a moving slider which was free to move in a horizontal direction along an aluminum $2 \times 2 \times \frac{1}{2}$ " angle. This aluminum angle was securely bolted at each extremity of the observation area and checked for level and cross-level by means of a machinist's level.

A steel tape was laid along the top surface of the angle for use in measuring horizontal distances. Vertical movement of the telescope was achieved by clamping the telescope on a depth probe which in turn was mounted on the slider.

At the point, about 1/2 mile from the shore,

The flow rate of the channel was estimated by means of a
calibrated vertical section located in the middle of the channel
side of the point. A differential water manometer was attached
to this section and the flow rate could be obtained by measuring
the difference in water levels. When applying the calibration

curves

$$Q = 1.000 V^3 \quad (2)$$

the flow rate and hence the velocity could be determined.

THE SURFACE PROFILE

A depth probe, calibrated in centimeters, was used to measure
the surface of the channel water, and continuous surface profiles and
to establish the vertical distance of the water surface. The probe was mounted
on a carriage which could be moved on rails located on top of the
flume.

A telescope apparatus shown in Fig. XI was used to measure the
horizontal distances. One end of the long arm of the telescope, mounted
on horizontal distance measuring wheels, was at horizontal distance
from the flume end of the probe. The telescope was mounted on
a sliding support which was free to move in a horizontal direction along
an aluminum 2 x 2 x 1/2 inch. This aluminum guide was secured by bolts
at each extremity of the observation area and showed the level and
cross-level by means of a mechanical level.

A small pipe was laid along the top surface of the flume for the
in measuring horizontal distances. Vertical movement of the telescope
was obtained by clamping the telescope in a depth probe which in turn
was mounted on the flume.

The procedure in using the telescope apparatus is as follows:
the slider is first moved to a desired position on the angle bar.
Then the probe carriage is moved along the length of the flume
until the probe tip is observed in the cross hair of the telescope.
This establishes the abscissa of the particular point on the wave
profile to be measured.

The procedure is using the following apparatus is as follows:
The slider is first moved to a desired position at the origin only.
Then the probe carriage is moved along the length of the glass
until the probe tip is cleared in the work part of the telescope.
This establishes the location of the particular point on the work
profile to be measured.

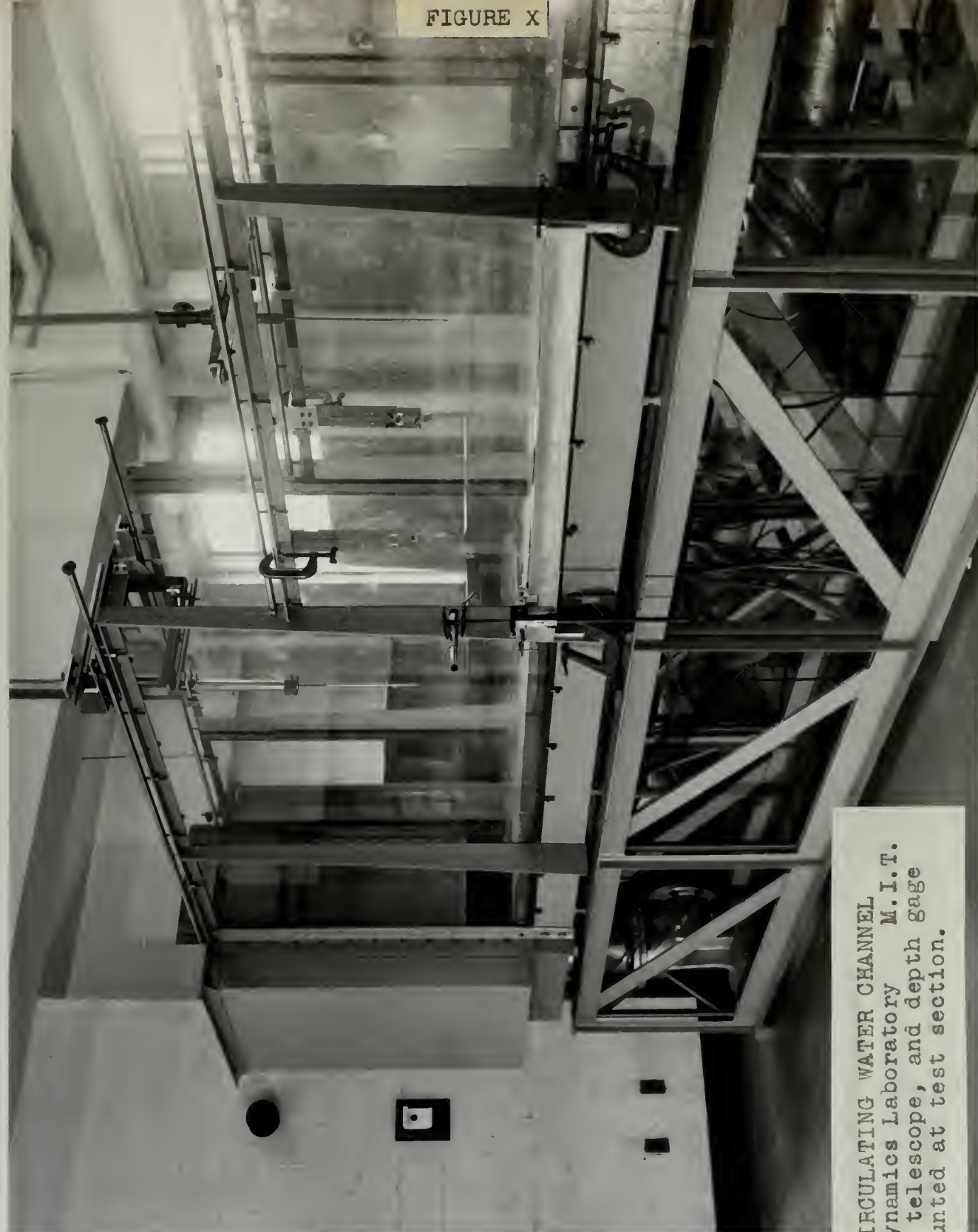
The following diagram illustrates the basic principle of the
telescope. The probe is mounted on a carriage which can move
along the length of the glass. The probe tip is positioned
at the desired point on the work part of the telescope.
The probe is then moved along the length of the glass until
the probe tip is cleared in the work part of the telescope.
This establishes the location of the particular point on the work
profile to be measured.

TABLE I
TABLE OF ORDINATES FOR NACA 4412
AIRFOIL SECTION

STATION	UPPER	LOWER	
0	-	0	
1.25	2.44	-1.43	
2.5	3.39	-1.95	
5.0	4.73	-2.49	Leading edge radius = 1.58
7.5	5.76	-2.74	Slope of radius through end of
10.0	6.59	-2.86	chord = $4/20$
15.0	7.89	-2.88	Max. mean camber = $.04 \times C$
20.0	8.80	-2.74	Location of max. mean
25.0	9.41	-2.50	camber = $.4 \times C$
30.0	9.76	-2.26	
40.0	9.80	-1.80	Max. thickness = $.12 \times C$
50.0	9.19	-1.40	
60.0	8.14	-1.00	
70.0	6.69	-0.65	
80.0	4.89	-0.39	
90.0	2.71	-0.22	
95.0	1.47	-0.16	
100.0	0.13	-0.13	
100.0	-	0	

In the above table the stations are expressed as percentages of the chord length. The ordinates to the upper and lower surfaces are also expressed as percentages of chord length.

The foil used in this investigation was designed for a chord length of 2.80 inches. The trailing edge had to be rounded off slightly to facilitate machining. The actual measured chord length was 2.77 inches.



CIRCULATING WATER CHANNEL
Hydrodynamics Laboratory M.I.T.
Foil, telescope, and depth gage
mounted at test section.



TELESCOPE
Close-up showing
mount and bench.



HYDROFOIL
Close-up of foil
and movable mount.

FIGURE XIII



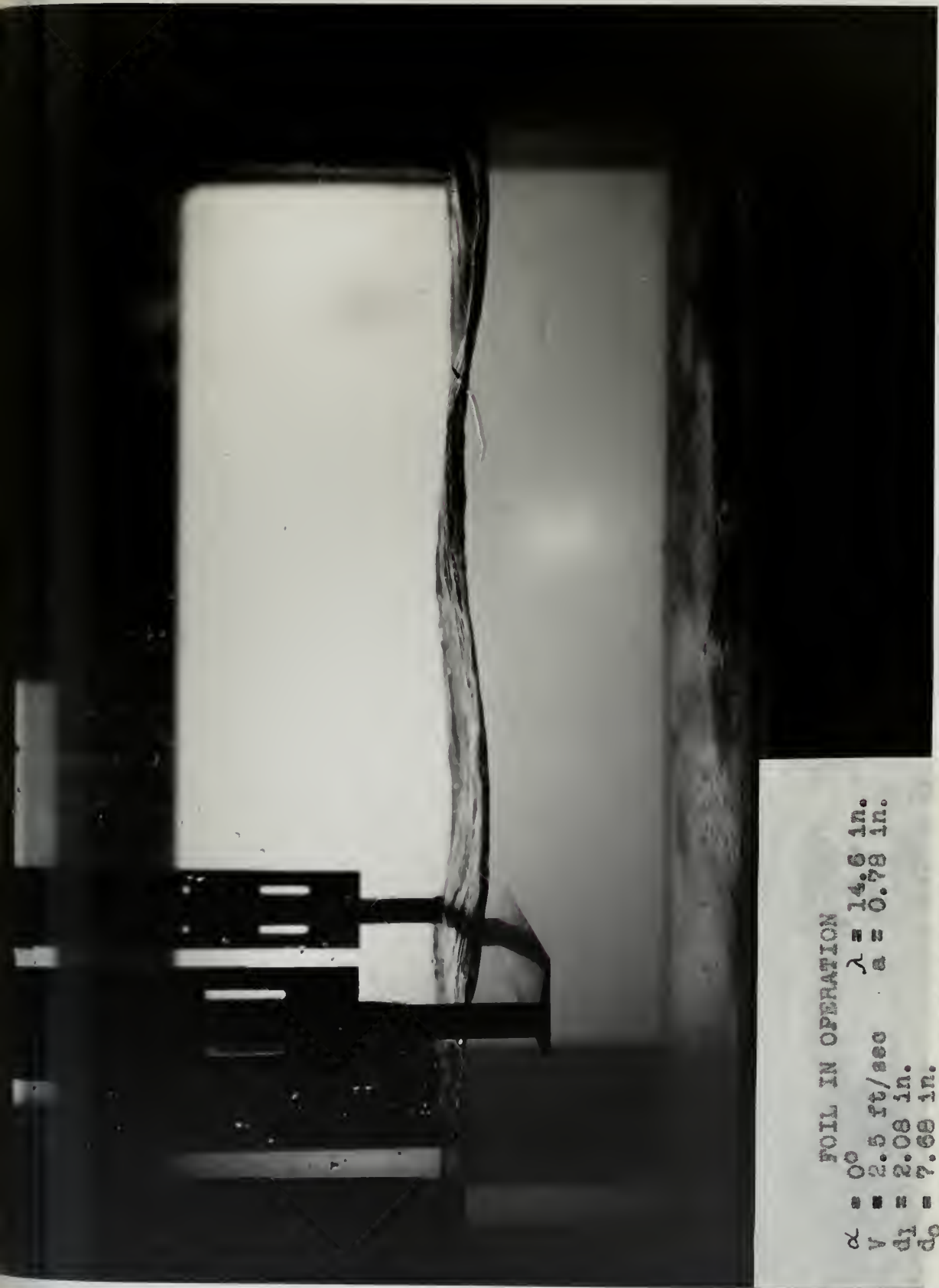
FOIL IN OPERATION

$\alpha = 0.6$
 $V = 2.0 \text{ ft/sec}$
 $d_1 = 3.46 \text{ in.}$
 $d_0 = 8.27 \text{ in.}$

$\lambda = 9.4 \text{ in.}$
 $a = 0.55 \text{ in.}$



FIGURE XIV



FOIL IN OPERATION

$\alpha = 0^\circ$
 $V = 2.5 \text{ ft/sec}$
 $d_1 = 2.08 \text{ in.}$
 $d_0 = 7.68 \text{ in.}$

$\lambda = 14.6 \text{ in.}$
 $a = 0.78 \text{ in.}$

Note surface rise above
hydrofoil.

APPENDIX B
SUMMARY OF DATA AND
CALCULATIONS

W. J. J. J. J. J.
W. J. J. J. J. J.
W. J. J. J. J. J.

TABLE II
SUMMARY OF EXPERIMENTAL DATA

RUN NO.	d ₁ in.	d ₀ in.	α °	V ft/sec	λ in.	a in.	y ₀ in.	y ₁ in.	l ₁ in.	l ₂ in.
7	2.94	9.95	2	1.30	4.5	0.17	0.13	-	2.2	5.0
8	2.92	10.24	2	1.83	8.0	0.50	0.37	-	3.9	R
9	2.94	6.72	2	1.40	5.7	0.42	0.23	-	2.6	5.6
10	2.93	9.03	2	1.72	7.3	0.61	0.30	-	3.8	7.6
11	2.97	7.77	2	1.60	6.1	0.44	0.24	-	2.9	6.6
12	2.94	8.70	2	1.19	4.1	0.13	0.16	-	2.2	4.6
13	2.94	7.20	2	1.98	8.4	0.72	0.43	-	4.2	R
14	2.90	4.75	2	1.32	5.5	0.34	0.16	-	2.3	5.7
15	2.99	6.44	2	1.29	4.8	0.29	0.18	-	2.3	5.5
16	2.93	7.70	2	1.31	5.0	0.24	0.16	-	2.7	5.4
17	2.93	6.72	2	2.51	16.0	1.30	0.64	-	6.5	14.2
18	2.91	4.44	2	2.51	19.3	1.46	0.77	-	7.6	17.0
19	2.97	5.57	2	2.48	16.0	1.40	0.66	-	6.0	14.7
20	2.54	6.95	2	2.24	12.0	1.10	0.45	-	5.2	R
21	3.01	6.32	2	2.03	9.2	0.61	0.43	-	4.0	R
22	3.02	8.4	2	1.99	9.2	0.62	0.47	-	3.9	R
23	2.94	9.2	2	1.97	8.6	0.58	0.37	-	4.2	R
24	2.93	4.66	2	2.01	11.0	0.37	0.52	-	5.2	R
25	2.03	3.53	2	2.00	12.2	0.85	0.63	-	5.3	R
26	2.00	7.5	2	1.84	8.3	0.48	0.41	-	4.4	R
27.5	2.00	7.5	2	2.06	10.1	0.85	0.47	-	5.0	R
28	2.00	7.5	2	2.30	12.0	1.02	0.47	-	6.0	R
29a	1.00	8.31	0	2.00	9.2	0.70	0.26	0.28	4.6	9.5
29b	1.76	8.31	0	2.00	9.4	0.76	0.27	0.16	4.6	9.5
29c	2.50	8.31	0	2.00	9.4	0.73	0.30	-	4.6	9.5
30a	3.51	8.31	0	2.00	10.0	0.57	0.21	-	4.6	9.5
30b	4.50	8.31	0	2.00	10.0	0.40	0.17	-	4.6	9.5
31a	4.88	8.31	2	2.00		0.42	0.22	-	4.2	9.7
31b	4.13	8.31	2	2.00		0.60	0.32	-	4.2	9.7
31c	3.44	8.31	2	2.00		0.78	0.38	-	4.2	9.7
36a	3.85	8.31	3	2.00		0.79	0.45	-	4.2	9.6
36b	4.98	8.31	3	2.00		0.42	0.28	-	4.2	9.6
36c	4.36	8.31	3	2.00		0.57	0.34	-	4.2	9.6
37a	2.64	8.31	1	2.00		0.81	0.43	-	4.2	9.7
37b	3.15	8.31	1	2.00		0.75	0.45	-	4.2	9.7
37c	3.86	8.31	1	2.00		0.62	0.36	-	4.2	9.7
37d	4.70	8.31	1	2.00		0.43	0.21	-	4.2	9.7
38a	4.96	8.31	-1	2.00		0.26	0.16	-	4.4	9.7
38b	4.05	8.31	-1	2.00		0.41	0.20	-	4.4	9.7
38c	3.15	8.31	-1	2.00		0.58	0.28	-	4.4	9.7
38d	2.25	8.31	-1	2.00		0.67	0.32	0.06	4.4	9.7
39	1.16	8.31	-1	2.00		0.64	0.26	0.22	4.4	9.7
40a	4.75	7.65	3	2.51		0.91	0.43	-	6.3	15.4
40b	3.77	7.65	3	2.51		1.20	0.55	-	6.3	15.4

TABLE II
(cont'd)

RUN NO.	d_1 in.	d_0 in.	α o	V ft/sec	λ in.	a in.	y_0 in.	y_1 in.	l_1 in.	l_2 in.
40c	2.76	7.65	3	2.51		1.34	0.63	-	6.3	15.4
40d	1.80	7.65	3	2.51		1.24	0.71	0.03	6.3	15.4
41a	0.82	7.65	3	2.51		0.92	0.49	0.24	6.3	15.4
41b	4.78	7.65	2	2.51		0.80	0.45	-	6.3	15.2
41c	3.77	7.65	2	2.51		1.09	0.52	-	6.3	15.2
41d	2.80	7.65	2	2.51		1.26	0.63	-	6.3	15.2
41e	1.80	7.65	2	2.51		1.18	0.57	0.08	6.3	15.2
41f	0.81	7.65	2	2.51		0.77	0.43	0.19	6.3	15.2
41g	4.80	7.65	1	2.51		0.70	0.39	-	6.4	15.3
41h	3.81	7.65	1	2.51		0.91	0.45	-	6.4	15.3
42a	2.84	7.65	1	2.51		1.05	0.49	0.04	6.4	15.3
42b	1.82	7.65	1	2.51		1.05	0.52	0.12	6.4	15.3
42c	0.84	7.65	1	2.51		0.74	0.38	0.20	6.4	15.3
42d	4.85	7.65	0			0.50	0.33	-	6.3	15.2
42e	3.85	7.65	0	2.51		0.65	0.37	-	6.3	15.2
42f	2.85	7.65	0	2.51		0.74	0.43	0.06	6.3	15.2
42g	1.85	7.65	0	2.51		0.78	0.45	0.10	6.3	15.2
42h	0.86	7.65	0	2.51		0.63	0.28	0.18	6.3	15.2
43a	4.85	7.65	-1	2.51		0.41	0.30	-	6.4	15.6
43b	3.86	7.65	-1	2.51		0.54	0.35	-	6.4	15.6
43c	2.84	7.65	-1	2.51		0.67	0.37	0.04	6.4	15.6
43d	1.85	7.65	-1	2.51		0.71	0.37	0.14	6.4	15.6
43e	0.87	7.65	-1	2.51		0.52	0.26	0.24	6.4	15.6
44a	2.98	9.65	3	1.50						
44b	3.72	9.65	3	1.50						
44c	4.50	9.65	3	1.50						
44d	3.42	9.65	3	1.50						
44e	3.01	9.65	2	1.50						
44f	3.51	9.65	2	1.50						
44g	4.04	9.65	2	1.50						
44h	3.02	9.65	1	1.50						
44i	3.54	9.65	1	1.50						
44j	4.05	9.65	1	1.50						
44k	2.57	9.65	0	1.50						
44l	3.04	9.65	0	1.50						
44m	3.54	9.65	0	1.50						
44n	2.55	9.65	-1	1.50						
44o	3.04	9.65	-1	1.50						
44p	3.58	9.65	-1	1.50						

This data not taken
in following runs

NOTE: 1) R in l_2 column indicates breaking at first wave crest.
2) - in y_1 column indicates no surface rise directly above foil.

Year	Month	Day	Time	Location	Event	Remarks
1900	Jan	1	10:00	St. Paul	Arrival	From New York
1900	Jan	2	10:00	St. Paul	Departure	For Chicago
1900	Jan	3	10:00	St. Paul	Arrival	From Chicago
1900	Jan	4	10:00	St. Paul	Departure	For New York
1900	Jan	5	10:00	St. Paul	Arrival	From New York
1900	Jan	6	10:00	St. Paul	Departure	For Chicago
1900	Jan	7	10:00	St. Paul	Arrival	From Chicago
1900	Jan	8	10:00	St. Paul	Departure	For New York
1900	Jan	9	10:00	St. Paul	Arrival	From New York
1900	Jan	10	10:00	St. Paul	Departure	For Chicago
1900	Jan	11	10:00	St. Paul	Arrival	From Chicago
1900	Jan	12	10:00	St. Paul	Departure	For New York
1900	Jan	13	10:00	St. Paul	Arrival	From New York
1900	Jan	14	10:00	St. Paul	Departure	For Chicago
1900	Jan	15	10:00	St. Paul	Arrival	From Chicago
1900	Jan	16	10:00	St. Paul	Departure	For New York
1900	Jan	17	10:00	St. Paul	Arrival	From New York
1900	Jan	18	10:00	St. Paul	Departure	For Chicago
1900	Jan	19	10:00	St. Paul	Arrival	From Chicago
1900	Jan	20	10:00	St. Paul	Departure	For New York
1900	Jan	21	10:00	St. Paul	Arrival	From New York
1900	Jan	22	10:00	St. Paul	Departure	For Chicago
1900	Jan	23	10:00	St. Paul	Arrival	From Chicago
1900	Jan	24	10:00	St. Paul	Departure	For New York
1900	Jan	25	10:00	St. Paul	Arrival	From New York
1900	Jan	26	10:00	St. Paul	Departure	For Chicago
1900	Jan	27	10:00	St. Paul	Arrival	From Chicago
1900	Jan	28	10:00	St. Paul	Departure	For New York
1900	Jan	29	10:00	St. Paul	Arrival	From New York
1900	Jan	30	10:00	St. Paul	Departure	For Chicago
1900	Jan	31	10:00	St. Paul	Arrival	From Chicago

(1) A person who has been convicted of a crime involving moral turpitude shall be ineligible for employment by the State or any political subdivision thereof.

(2) A person who has been convicted of a crime involving moral turpitude shall be ineligible for employment by the State or any political subdivision thereof.

TABLE II
(cont'd)

Limits of accuracy in terms of probable error.

d_1	0.02	in.
d_0	0.02	in.
α	0.1°	
v	0.01	ft/sec.
λ	0.3	in.
a	0.05	in.
y_0	0.02	in.
y_1	0.02	in.
l_1	0.2	in.
l_2	0.4	in.

λ	λ/λ_0	λ/λ_0	λ/λ_0	λ/λ_0	λ/λ_0
1.0	1.000	1.000	1.000	1.000	1.000
1.1	0.909	1.100	0.909	1.100	0.909
1.2	0.833	1.200	0.833	1.200	0.833
1.3	0.769	1.300	0.769	1.300	0.769
1.4	0.714	1.400	0.714	1.400	0.714
1.5	0.667	1.500	0.667	1.500	0.667
1.6	0.625	1.600	0.625	1.600	0.625
1.7	0.588	1.700	0.588	1.700	0.588
1.8	0.556	1.800	0.556	1.800	0.556
1.9	0.526	1.900	0.526	1.900	0.526
2.0	0.500	2.000	0.500	2.000	0.500

Limitations of λ_1 , λ_2 , and λ_3 are shown in terms of λ in the above table. The limits of accuracy in terms of the standard deviation of the measured quantities are shown in the same table. The limits of accuracy in terms of the standard deviation of the measured quantities are shown in the same table.

$$\frac{\lambda}{\lambda_0} = \left(\frac{\lambda}{\lambda_0} \right)^2$$

where λ_0 is the wavelength of the light.

TABLE III

TABULATION OF DATA FOR THE PLOT OF THE VARIATION
OF WAVE-LENGTH WITH DEPTH OF WATER TO
NOTE SHALLOW-WATER EFFECTS

V = 1.30 ft./sec.		$\alpha = 2^\circ$		$d_1 = 2.940$ in.	
Run	do(ft.)	V ft./sec.	V ²	λ ft.	λ (corrected)
7	0.829	1.300	1.69	0.375	0.375
9	0.560	1.485	2.21	0.475	0.363
10	0.752	1.720	2.96	0.608	0.347
11	0.647	1.595	2.55	0.508	0.337
14	0.396	1.320	1.75	0.458	0.413
15	0.536	1.294	1.68	0.396	0.398
16	0.641	1.310	1.72	0.416	0.408

V = 2.00 ft./sec.		$\alpha = 2^\circ$		$d_1 = 2.940$ in.	
Run	do	V	V ²	λ	λ (corrected)
13	0.600	1.975	3.90	0.700	0.718
20	0.579	2.240	5.02	1.000	0.798
21	0.526	2.030	4.13	0.766	0.742
22	0.700	1.990	3.96	0.766	0.774
23	0.718	1.972	3.89	0.716	0.736
24	0.388	2.010	4.04	0.917	0.908
25	0.294	2.000	4.00	1.017	1.017
30	0.689	1.980	3.93	0.750	0.764

V = 2.5 ft./sec.		$\alpha = 2^\circ$		$d_1 = 2.94$ in.	
Run	do	V	V ²	λ	λ (corrected)
17	0.559	2.510	6.32	1.333	1.319
18	0.370	2.510	6.32	1.608	1.59
19	0.464	2.480	6.15	1.333	1.356
40	0.636	2.510	6.32	1.250	1.245

Velocities of 1.3, 2.0, and 2.5 ft./sec. were chosen to show on the curve because most of the runs made during the early part of the investigation were at velocities near these. As shown above all of the wave-lengths were corrected by proportioning based on the ratio of the square of the velocities

$$\frac{\lambda_1}{\lambda_2} = \left(\frac{V_1}{V_2} \right)^2 \quad (3)$$

which was previously established.

MONITORING AND CONTROL OF THE VARIATION
OF WATER QUALITY WITH RESPECT TO
SOURCES OF POLLUTION

[illegible]

λ	μ	ν	ξ	η	θ
0.000	0.000	0.000	0.000	0.000	0.000
0.001	0.001	0.001	0.001	0.001	0.001
0.002	0.002	0.002	0.002	0.002	0.002
0.003	0.003	0.003	0.003	0.003	0.003
0.004	0.004	0.004	0.004	0.004	0.004
0.005	0.005	0.005	0.005	0.005	0.005
0.006	0.006	0.006	0.006	0.006	0.006
0.007	0.007	0.007	0.007	0.007	0.007
0.008	0.008	0.008	0.008	0.008	0.008
0.009	0.009	0.009	0.009	0.009	0.009
0.010	0.010	0.010	0.010	0.010	0.010

λ	μ	ν	ξ	η	θ
0.00	0.00	0.00	0.00	0.00	0.00
0.01	0.01	0.01	0.01	0.01	0.01
0.02	0.02	0.02	0.02	0.02	0.02
0.03	0.03	0.03	0.03	0.03	0.03
0.04	0.04	0.04	0.04	0.04	0.04
0.05	0.05	0.05	0.05	0.05	0.05
0.06	0.06	0.06	0.06	0.06	0.06
0.07	0.07	0.07	0.07	0.07	0.07
0.08	0.08	0.08	0.08	0.08	0.08
0.09	0.09	0.09	0.09	0.09	0.09
0.10	0.10	0.10	0.10	0.10	0.10

Velocities of 1.1, 1.4, and 2.5 ft/sec. were chosen to make an 800-
watt hydraulic load of the pump and driving the water part of the investi-
gation more of velocity than power. As shown above all of the above
findings were observed in non-Newtonian cases as the fluids of the range of

$$\left(\frac{1}{2}\right) = \frac{1}{2}$$

which are positively correlated.

TABLE IV

TABULATION OF DATA FOR THE PLOT OF VELOCITY VS
WAVE-LENGTH FOR SHIP WATER OPERATIONS

Run	V	λ	λ'
8	1.83	8.00	.666
10	1.72	7.30	.608
11	1.595	6.10	.508
17	2.51	16.00	1.334
20	2.24	12.00	1.00
22	1.99	9.20	.766
23	1.97	8.60	.716
26	1.835	8.30	.692
26.5	2.45	14.0	1.166
29-30	1.98	9.6	.800
40	2.48	15.00	1.25

The following calculations serve to substantiate the theory. From the curve of velocity versus wave-length the following points were taken:

$$\begin{aligned}\lambda &= 1.76 \text{ ft.} & V &= 3.00 \text{ ft./sec.} \\ \lambda &= 0.44 \text{ ft.} & V &= 1.50 \text{ ft./sec.}\end{aligned}$$

The equation is of the form:

$$\lambda = KV^n \quad (4)$$

$$(1.76 = K(3.00)^n$$

$$(0.44 = K(1.50)^n$$

$$\ln \lambda = \ln K + n(\ln V)$$

$$\ln 1.76 = \ln K + n \ln 3.00$$

$$\ln 0.44 = \ln K + n \ln 1.50$$

$$0.565 = \ln K + n 1.098$$

$$-0.823 = \ln K + n 0.405$$

$$1.388 = 0.693 n$$

$$\therefore n = 2$$

$$0.565 = \ln K + 2 (1.098)$$

$$\ln K = -1.631$$

$$K = 0.195$$

$$\therefore \lambda = 0.195 V^2 = \frac{2\pi}{6} V^2$$

VI

TABLE IV
 SUMMARY OF DATA FOR THE STUDY OF THE EFFECT OF TEMPERATURE ON THE RATE OF REACTION

Temp. (°C)	k (min ⁻¹)	ln k	1/T (°K ⁻¹)
25.0	0.0012	-6.73	0.00336
30.0	0.0025	-5.99	0.00323
35.0	0.0050	-5.29	0.00310
40.0	0.0100	-4.61	0.00298
45.0	0.0200	-3.91	0.00286
50.0	0.0400	-3.22	0.00274
55.0	0.0800	-2.53	0.00263
60.0	0.1600	-1.83	0.00252
65.0	0.3200	-1.14	0.00241
70.0	0.6400	-0.44	0.00230

The following table gives the values of the rate constant k for the reaction at various temperatures. The values of k were determined from the slope of the straight line obtained from a plot of ln k versus 1/T.

$$k = A e^{-E_a/RT}$$

$$\ln k = \ln A - E_a/RT$$

The equation of the line is:

$$\ln k = -1.75 \times 10^4 / T + 12.5$$

$$E_a = 17.5 \text{ kcal/mole}$$

$$\ln A = 12.5$$

$$A = 2.7 \times 10^5 \text{ min}^{-1}$$

$$\ln k = -1.75 \times 10^4 / T + 12.5$$

$$\ln 0.0012 = -1.75 \times 10^4 / T + 12.5$$

$$-6.73 = -1.75 \times 10^4 / T + 12.5$$

$$-19.23 = -1.75 \times 10^4 / T$$

$$T = 1.15 \times 10^5 / 19.23 = 5980 \text{ } ^\circ\text{K}$$

$$T = 5980 \text{ } ^\circ\text{K} = 5707 \text{ } ^\circ\text{C}$$

$$T = 5707 \text{ } ^\circ\text{C} = 10413 \text{ } ^\circ\text{F}$$

$$T = 5707 \text{ } ^\circ\text{C} = 10413 \text{ } ^\circ\text{F}$$

$$x = \frac{1}{\sqrt{2}} \quad y = \frac{1}{\sqrt{2}} \quad z = \frac{1}{\sqrt{2}} \quad w = \frac{1}{\sqrt{2}}$$
$$\alpha_1 = \beta_1 \quad \alpha_2 = \beta_2 \quad \alpha_3 = \beta_3 \quad \alpha_4 = \beta_4 \quad \alpha_5 = \beta_5$$
[illegible]
$$V = 5.00 \text{ m/s} \quad F_1 = 0.333 \quad a = 0.71 \text{ m/s}^2$$
$$\alpha_1 = 30 \quad \alpha_2 = 30 \quad \alpha_3 = 30 \quad \alpha_4 = 30 \quad \alpha_5 = 30$$
[illegible]
$$V = 1.20 \text{ m/s} \quad f = 0.750 \text{ Hz} \quad \Delta t = 0.001 \text{ s}$$
$$a_1 = 1, a_2 = 2, a_3 = 3, a_4 = 4, a_5 = 5, a_6 = 6, a_7 = 7, a_8 = 8, a_9 = 9, a_{10} = 10$$

2/0	2/2	2/4	2/6	2/8	2/10	2/12	2/14	2/16	2/18
270.1	271.0	272.1	273.0	274.1	275.0	276.1	277.0	278.1	279.0
280.1	281.0	282.1	283.0	284.1	285.0	286.1	287.0	288.1	289.0
290.1	291.0	292.1	293.0	294.1	295.0	296.1	297.0	298.1	299.0
300.1	301.0	302.1	303.0	304.1	305.0	306.1	307.0	308.1	309.0

TABLE VI
NUMERICAL AVERAGES RELATING THE
TRANSITION TO THE STEADY WAVE

Run	$y_0/a(\%)$	Run	$L_1/\lambda(\%)$	Run	$\frac{L_2}{\lambda}$
31a	52	7	49	7	1.11
b	54	8	49	9	0.98
c	50	9	46	10	1.04
36a	57	10	52	11	1.08
b	67	11	48	12	1.11
c	59	12	54	13	1.04
37a	53	13	49	15	1.14
b	60	15	48	16	1.08
c.	58	16	54	29a	1.03
d	49	23	49	29b	1.01
38a	62	26	53	29c	1.01
b	49	27.5	50	30a	0.95
c	48	28	50	30b	0.95
d	48				
39	44				
40a	47	Avg.	50	Avg.	1.04
b	46	Min.	46	Min.	0.95
c	47	Max.	54	Max.	1.14
d	57				
41a	53				
b	56				
c	48				
d	51				
e	48				
f	56				
g	56				
h	50				
42a	47				
b	50				
c	51				
d	66				
e	57				
f	58				
g	58				
h	44				
43b	65				
c	55				
d	52				
e	50				
Avg.	53.3				
Min.	44				
Max.	67				

TABLE VI

OVERALL AVERAGE MEASUREMENTS
OBTAINED BY THE STUDENT

$\frac{d}{\lambda}$	mm	λ (Å)	mm	$\frac{d}{\lambda}$ (2)	mm
11.1	1	21	1	21	11.1
12.0	2	22	2	22	12.0
13.1	3	23	3	23	13.1
14.0	4	24	4	24	14.0
15.1	5	25	5	25	15.1
16.0	6	26	6	26	16.0
17.1	7	27	7	27	17.1
18.0	8	28	8	28	18.0
19.1	9	29	9	29	19.1
20.0	10	30	10	30	20.0
21.1	11	31	11	31	21.1
22.0	12	32	12	32	22.0
23.1	13	33	13	33	23.1
24.0	14	34	14	34	24.0
25.1	15	35	15	35	25.1
26.0	16	36	16	36	26.0
27.1	17	37	17	37	27.1
28.0	18	38	18	38	28.0
29.1	19	39	19	39	29.1
30.0	20	40	20	40	30.0
31.1	21	41	21	41	31.1
32.0	22	42	22	42	32.0
33.1	23	43	23	43	33.1
34.0	24	44	24	44	34.0
35.1	25	45	25	45	35.1
36.0	26	46	26	46	36.0
37.1	27	47	27	47	37.1
38.0	28	48	28	48	38.0
39.1	29	49	29	49	39.1
40.0	30	50	30	50	40.0
41.1	31	51	31	51	41.1
42.0	32	52	32	52	42.0
43.1	33	53	33	53	43.1
44.0	34	54	34	54	44.0
45.1	35	55	35	55	45.1
46.0	36	56	36	56	46.0
47.1	37	57	37	57	47.1
48.0	38	58	38	58	48.0
49.1	39	59	39	59	49.1
50.0	40	60	40	60	50.0
51.1	41	61	41	61	51.1
52.0	42	62	42	62	52.0
53.1	43	63	43	63	53.1
54.0	44	64	44	64	54.0
55.1	45	65	45	65	55.1
56.0	46	66	46	66	56.0
57.1	47	67	47	67	57.1
58.0	48	68	48	68	58.0
59.1	49	69	49	69	59.1
60.0	50	70	50	70	60.0
61.1	51	71	51	71	61.1
62.0	52	72	52	72	62.0
63.1	53	73	53	73	63.1
64.0	54	74	54	74	64.0
65.1	55	75	55	75	65.1
66.0	56	76	56	76	66.0
67.1	57	77	57	77	67.1
68.0	58	78	58	78	68.0
69.1	59	79	59	79	69.1
70.0	60	80	60	80	70.0
71.1	61	81	61	81	71.1
72.0	62	82	62	82	72.0
73.1	63	83	63	83	73.1
74.0	64	84	64	84	74.0
75.1	65	85	65	85	75.1
76.0	66	86	66	86	76.0
77.1	67	87	67	87	77.1
78.0	68	88	68	88	78.0
79.1	69	89	69	89	79.1
80.0	70	90	70	90	80.0
81.1	71	91	71	91	81.1
82.0	72	92	72	92	82.0
83.1	73	93	73	93	83.1
84.0	74	94	74	94	84.0
85.1	75	95	75	95	85.1
86.0	76	96	76	96	86.0
87.1	77	97	77	97	87.1
88.0	78	98	78	98	88.0
89.1	79	99	79	99	89.1
90.0	80	100	80	100	90.0
91.1	81	101	81	101	91.1
92.0	82	102	82	102	92.0
93.1	83	103	83	103	93.1
94.0	84	104	84	104	94.0
95.1	85	105	85	105	95.1
96.0	86	106	86	106	96.0
97.1	87	107	87	107	97.1
98.0	88	108	88	108	98.0
99.1	89	109	89	109	99.1
100.0	90	110	90	110	100.0

TABLE VII

SAMPLE DATA SHEET (RUN 29a)

Manometer 1.30 feet, $\alpha \approx 0^\circ$

Foil Location: vertical 35.25 cm., horizontal 16.70 cm.

PROFILE DATA

VERTICAL	HORIZONTAL	VERTICAL	HORIZONTAL
36.75	11.00	35.80	31.00
36.76	13.00	35.97	32.00
36.79	14.00	36.56	33.00
36.92	15.00	37.41	34.00
36.98	16.00	37.75	35.00
37.42	17.00	37.19	36.50
37.47	17.40	36.11	38.00
37.61	18.20	35.86	39.50
37.01	19.00	36.08	41.00
36.57	20.00	36.87	42.50
36.25	21.00	37.36	44.00
36.10	22.00		
36.31	23.00		
36.69	24.00		
37.25	25.00		
37.75	26.00		
37.55	27.00		
37.09	28.00		
36.50	29.00		
36.15	30.00		

The above is data for one of the runs in which a complete profile was mapped. Vertical distances are recorded in centimeters and horizontal distances are recorded in inches. Bottom elevation was 15.75 cm.

... ..

Bottom elevation was 15.75 cm.

TABLE VIII

SAMPLE DATA SHEET (RUN 41b)

Manometer 1.77 feet, $\alpha = 2^\circ$.

Foil location: vertical 23.09 cm., horizontal 16.40 cm.

<u>VERTICAL (cm.)</u>	<u>HORIZONTAL (in.)</u>	
35.22	11.00	Max. (Vert. 33.92 cm. (Hori. 40.40 in.
35.22	13.00	
35.22	15.00	
35.01	17.00	Min. (Vert. 35.82 cm. (Hori. 48.80 in.
34.64	19.00	
34.28	21.00	
34.11	23.00	
34.44	25.00	
34.95	27.00	
35.58	29.00	
35.95	31.00	
35.80	33.00	
35.45	35.00	

The above table is data for one of the runs of the series in which the transient was to be studied and the amplitude was to be noted.

TABLE 1. - SUMMARY OF DATA

For the purpose of this report, the data were divided into two groups, (a) data for the period 1940-1945, and (b) data for the period 1946-1950.

Year	Value
1940	12.5
1941	13.2
1942	14.1
1943	15.0
1944	16.0
1945	17.0
1946	18.0
1947	19.0
1948	20.0
1949	21.0
1950	22.0

The above table is a summary of the data for the period 1940-1950. The data were obtained from the records of the Bureau of the Census, and are subject to the usual errors of such records.

TABLE IX

SAMPLE DATA SHEET (RUN 4ba)

Manometer 1.015 feet, $\alpha = 3^\circ$, $d_0 = 40.25$ cm.
 Foil location: vertical 32.68 cm.

Max.	40.75 cm.
Min.	39.60 cm.
Max.	40.64 cm.
Min.	39.69 cm.
Max.	40.84 cm.
Min.	39.59 cm.

The above is data from a run of a series in which amplitude only was studied.

REMARKS

WATER LEVEL 1000

△△△△△

$\alpha = 0.05$, $n = 30$, and $Z_{\alpha/2} = 1.96$

१	२	३
४	५	६
७	८	९
१०	११	१२
१३	१४	१५
१६	१७	१८
१९	२०	२१
२२	२३	२४
२५	२६	२७
२८	२९	३०
३१	३२	३३
३४	३५	३६
३७	३८	३९
४०	४१	४२
४३	४४	४५
४६	४७	४८
४९	५०	५१
५२	५३	५४
५५	५६	५७
५८	५९	६०
६१	६२	६३
६४	६५	६६
६७	६८	६९
७०	७१	७२
७३	७४	७५
७६	७७	७८
७९	८०	८१
८२	८३	८४
८५	८६	८७
८८	८९	९०
९१	९२	९३
९४	९५	९६
९७	९८	९९
१००	१०१	१०२
१०३	१०४	१०५
१०६	१०७	१०८
१०९	११०	१११
११२	११३	११४
११५	११६	११७
११८	११९	१२०
१२१	१२२	१२३
१२४	१२५	१२६
१२७	१२८	१२९
१३०	१३१	१३२
१३३	१३४	१३५
१३६	१३७	१३८
१३९	१४०	१४१
१४२	१४३	१४४
१४५	१४६	१४७
१४८	१४९	१५०
१५१	१५२	१५३
१५४	१५५	१५६
१५७	१५८	१५९
१६०	१६१	१६२
१६३	१६४	१६५
१६६	१६७	१६८
१६९	१७०	१७१
१७२	१७३	१७४
१७५	१७६	१७७
१७८	१७९	१८०
१८१	१८२	१८३
१८४	१८५	१८६
१८७	१८८	१८९
१९०	१९१	१९२
१९३	१९४	१९५
१९६	१९७	१९८
१९९	२००	२०१
२०२	२०३	२०४
२०५	२०६	२०७
२०८	२०९	२१०
२११	२१२	२१३
२१४	२१५	२१६
२१७	२१८	२१९
२२०	२२१	२२२
२२३	२२४	२२५
२२६	२२७	२२८
२२९	२३०	२३१
२३२	२३३	२३४
२३५	२३६	२३७
२३८	२३९	२४०
२४१	२४२	२४३
२४४	२४५	२४६
२४७	२४८	२४९
२५०	२५१	२५२
२५३	२५४	२५५
२५६	२५७	२५८
२५९	२६०	२६१
२६२	२६३	२६४
२६५	२६६	२६७
२६८	२६९	२७०
२७१	२७२	२७३
२७४	२७५	२७६
२७७	२७८	२७९
२८०	२८१	२८२
२८३	२८४	२८५
२८६	२८७	२८८
२८९	२९०	२९१
२९२	२९३	२९४
२९५	२९६	२९७
२९८	२९९	३००
३०१	३०२	३०३
३०४	३०५	३०६
३०७	३०८	३०९
३१०	३११	३१२
३१३	३१४	३१५
३१६	३१७	३१८
३१९	३२०	३२१
३२२	३२३	३२४
३२५	३२६	३२७
३२८	३२९	३३०
३३१	३३२	३३३
३३४	३३५	३३६
३३७	३३८	३३९
३४०		

The above is also true of a number of other diseases.

• *halimite 500*

APPENDIX CSAMPLE INTERMEDIATE PLOTS

THE
UNITED STATES OF AMERICA

IN SENATE

REPORT
OF THE
COMMISSIONER
OF THE
GENERAL LAND OFFICE

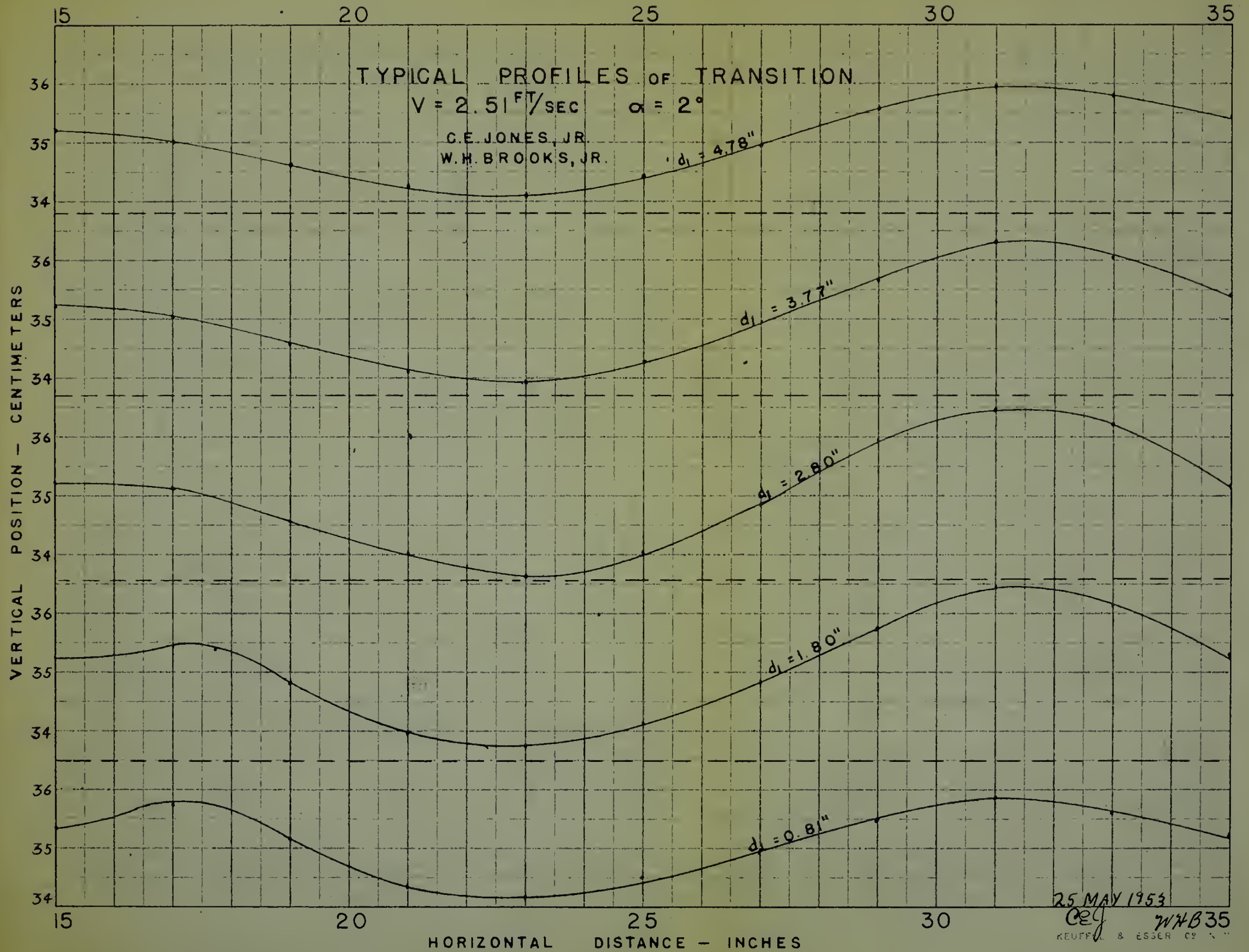
FOR THE YEAR 1894

WASHINGTON

APPENDIX

STATE OF CALIFORNIA

FIGURE XV



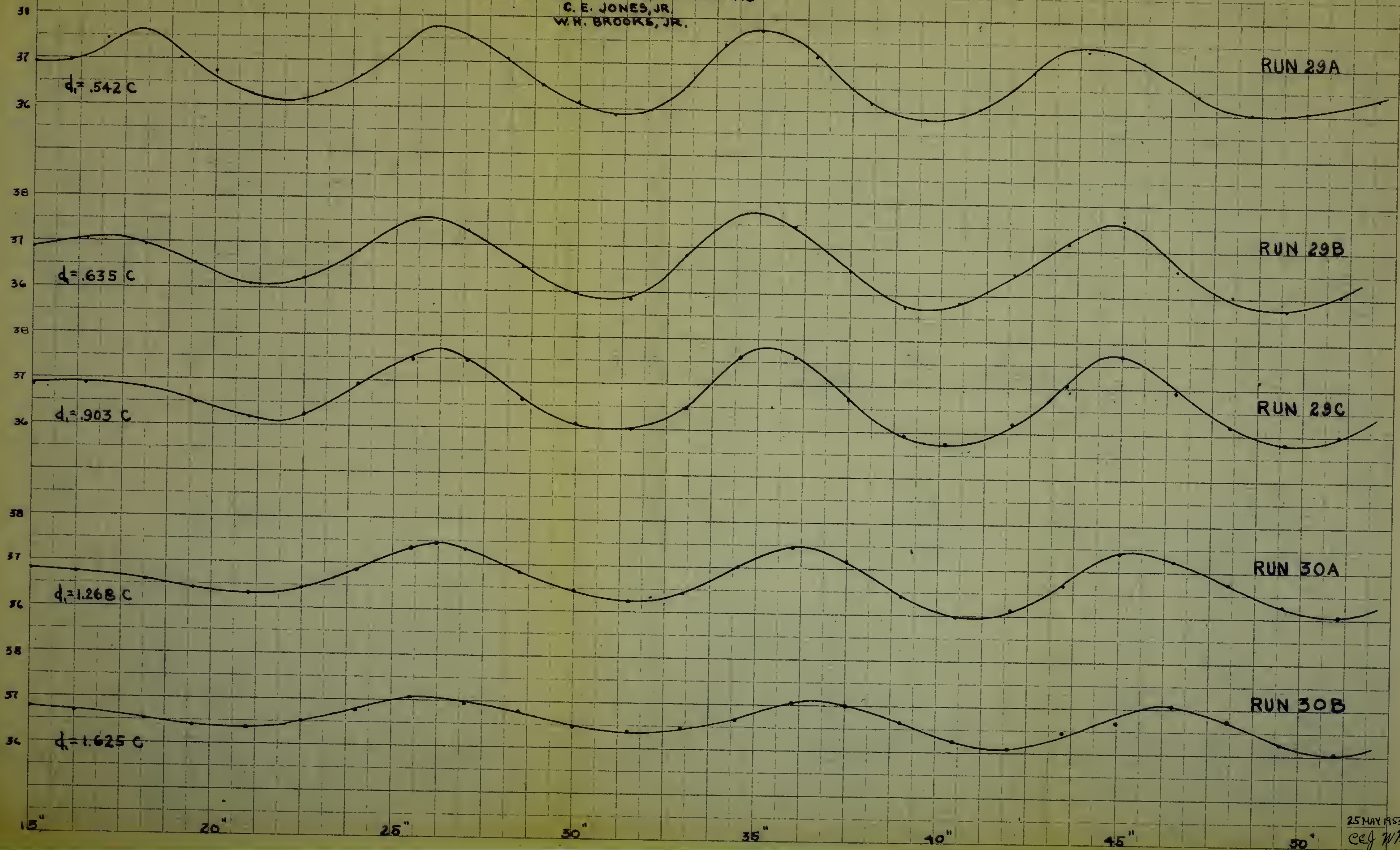
THE
UNITED STATES DEPARTMENT OF AGRICULTURE

OFFICE OF THE ASSISTANT SECRETARY
WASHINGTON, D. C.

1917	1918	1919
1920	1921	1922
1923	1924	1925
1926	1927	1928
1929	1930	1931
1932	1933	1934
1935	1936	1937
1938	1939	1940
1941	1942	1943
1944	1945	1946
1947	1948	1949
1950	1951	1952
1953	1954	1955
1956	1957	1958
1959	1960	1961
1962	1963	1964
1965	1966	1967
1968	1969	1970
1971	1972	1973
1974	1975	1976
1977	1978	1979
1980	1981	1982
1983	1984	1985
1986	1987	1988
1989	1990	1991
1992	1993	1994
1995	1996	1997
1998	1999	2000
2001	2002	2003
2004	2005	2006
2007	2008	2009
2010	2011	2012
2013	2014	2015
2016	2017	2018
2019	2020	2021
2022	2023	2024
2025	2026	2027
2028	2029	2030
2031	2032	2033
2034	2035	2036
2037	2038	2039
2040	2041	2042
2043	2044	2045
2046	2047	2048
2049	2050	2051
2052	2053	2054
2055	2056	2057
2058	2059	2060
2061	2062	2063
2064	2065	2066
2067	2068	2069
2070	2071	2072
2073	2074	2075
2076	2077	2078
2079	2080	2081
2082	2083	2084
2085	2086	2087
2088	2089	2090
2091	2092	2093
2094	2095	2096
2097	2098	2099
2100	2101	2102
2103	2104	2105
2106	2107	2108
2109	2110	2111
2112	2113	2114
2115	2116	2117
2118	2119	2120
2121	2122	2123
2124	2125	2126
2127	2128	2129
2130	2131	2132
2133	2134	2135
2136	2137	2138
2139	2140	2141
2142	2143	2144
2145	2146	2147
2148	2149	2150
2151	2152	2153
2154	2155	2156
2157	2158	2159
2160	2161	2162
2163	2164	2165
2166	2167	2168
2169	2170	2171
2172	2173	2174
2175	2176	2177
2178	2179	2180
2181	2182	2183
2184	2185	2186
2187	2188	2189
2190	2191	2192
2193	2194	2195
2196	2197	2198
2199	2200	2201
2202	2203	2204
2205	2206	2207
2208	2209	2210
2211	2212	2213
2214	2215	2216
2217	2218	2219
2220	2221	2222
2223	2224	2225
2226	2227	2228
2229	2230	2231
2232	2233	2234
2235	2236	2237
2238	2239	2240
2241	2242	2243
2244	2245	2246
2247	2248	2249
2250	2251	2252
2253	2254	2255
2256	2257	2258
2259	2260	2261
2262	2263	2264
2265	2266	2267
2268	2269	2270
2271	2272	2273
2274	2275	2276
2277	2278	2279
2280	2281	2282
2283	2284	2285
2286	2287	2288
2289	2290	2291
2292	2293	2294
2295	2296	2297
2298	2299	2300
2301	2302	2303
2304	2305	2306
2307	2308	2309
2310	2311	2312
2313	2314	2315
2316	2317	2318
2319	2320	2321
2322	2323	2324
2325	2326	2327
2328	2329	2330
2331	2332	2333
2334	2335	2336
2337	2338	2339
2340	2341	2342
2343	2344	2345
2346	2347	2348
2349	2350	2351
2352	2353	2354
2355	2356	2357
2358	2359	2360
2361	2362	2363
2364	2365	2366
2367	2368	2369
2370	2371	2372
2373	2374	2375
2376	2377	2378
2379	2380	2381
2382	2383	2384
2385	2386	2387
2388	2389	2390
2391	2392	2393
2394	2395	2396
2397	2398	2399
2400	2401	2402
2403	2404	2405
2406	2407	2408
2409	2410	2411
2412	2413	2414
2415	2416	2417
2418	2419	2420
2421	2422	2423
2424	2425	2426
2427	2428	2429
2430	2431	2432
2433	2434	2435
2436	2437	2438
2439	2440	2441
2442	2443	2444
2445	2446	2447
2448	2449	2450
2451	2452	2453
2454	2455	2456
2457	2458	2459
2460	2461	2462
2463	2464	2465
2466	2467	2468
2469	2470	2471
2472	2473	2474
2475	2476	2477
2478	2479	2480
2481	2482	2483
2484	2485	2486
2487	2488	2489
2490	2491	2492
2493	2494	2495
2496	2497	2498
2499	2500	2501
2502	2503	2504
2505	2506	2507
2508	2509	2510
2511	2512	2513
2514	2515	2516
2517	2518	2519
2520	2521	2522
2523	2524	2525
2526	2527	2528
2529	2530	2531
2532	2533	2534
2535	2536	2537
2538	2539	2540
2541	2542	2543
2544	2545	2546
2547	2548	2549
2550	2551	2552
2553	2554	2555
2556	2557	2558
2559	2560	2561
2562	2563	2564
2565	2566	2567
2568	2569	2570
2571	2572	2573
2574	2575	2576
2577	2578	2579
2580	2581	2582
2583	2584	2585
2586	2587	2588
2589	2590	2591
2592	2593	2594
2595	2596	2597
2598	2599	2600
2601	2602	2603
2604	2605	2606
2607	2608	2609
2610	2611	2612
2613	2614	2615
2616	2617	2618
2619	2620	2621
2622	2623	2624
2625	2626	2627
2628	2629	2630
2631	2632	2633
2634	2635	2636
2637	2638	2639
2640	2641	2642
2643	2644	2645
2646	2647	2648
2649	2650	2651
2652	2653	2654
2655	2656	2657
2658	2659	2660
2661	2662	2663
2664	2665	2666
2667	2668	2669
2670	2671	2672
2673	2674	2675
2676	2677	2678
2679	2680	2681
2682	2683	2684
2685	2686	2687
2688	2689	2690
2691	2692	2693
2694	2695	2696
2697	2698	2699
2700	2701	2702
2703	2704	2705
2706	2707	2708
2709	2710	2711
2712	2713	2714
2715	2716	2717
2718	2719	2720
2721	2722	2723
2724	2725	2726
2727	2728	2729
2730	2731	2732
2733	2734	2735
2736	2737	2738
2739	2740	2741
2742	2743	2744
2745	2746	2747
2748	2749	2750
2751	2752	2753
2754	2755	2756
2757	2758	2759
2760	2761	2762
2763	2764	2765
2766	2767	2768
2769	2770	2771
2772	2773	2774
2775	2776	2777
2778	2779	2780
2781	2782	2783
2784	2785	2786
2787	2788	2789
2790	2791	2792
2793	2794	2795
2796	2797	2798
2799	2800	2801
2802	2803	2804
2805	2806	2807
2808	2809	2810
2811	2812	2813
2814	2815	2816
2817	2818	2819
2820	2821	2822
2823	2824	2825
2826	2827	2828
2829	2830	2831
2832	2833	2834
2835	2836	2837
2838	2839	2840
2841	2842	2843
2844	2845	2846
2847	2848	2849
2850	2851	2852
2853	2854	2855
2856	2857	2858
2859	2860	2861
2862	2863	2864
2865	2866	2867
2868	2869	2870
2871	2872	2873
2874	2875	2876
2877	2878	2879
2880	2881	2882
2883	2884	2885
2886	2887	2888
2889	2890	2891
2892	2893	2894
2895	2896	2897
2898	2899	2900
2901	2902	2903
2904	2905	2906
2907	2908	2909
2910	2911	2912
2913	2914	2915
2916	2917	2918
2919	2920	2921
2922	2923	2924
2925	2926	2927
2928	2929	2930
2931	2932	2933
2934	2935	2936
2937	2938	2939
2940	2941	2942
2943	2944	2945
2946	2947	2948
2949	2950	2951
2952	2953	2954
2955	2956	2957
2958	2959	2960
2961	2962	2963
2964	2965	2966
2967	2968	2969
2970	2971	2972
2973	2974	2975
2976	2977	2978
2979	2980	2981
2982	2983	2984
2985	2986	2987
2988	2989	2990
2991	2992	2993
2994	2995	2996
2997	2998	2999
3000	3001	3002
3003	3004	3005
3006	3007	3008
3009	3010	3011
3012	3013	3014
3015	3016	3017
3018	3019	3020
3021	3022	3023
3024	3025	3026
3027	3028	3029
3030	3031	3032
3033	3034	3035
3036	3037	3038
3039	3040	3041
3042	3043	3044
3045	3046	3047
3048	3049	3050
3051	3052	3053
3054	3055	3056
3057	3058	3059
3060	3061	3062
3063	3064	3065
3066	3067	3068
3069	3070	3071
3072	3073	3074
3075	3076	3077
3078	3079	3080
3081	3082	3083
3084	3085	3086
3087	3088	3089
3090	3091	3092
3093	3094	3095
3096	3097	3098
3099	3100	3101
3102	3103	

FIGURE XVI

PLOT OF WAVE PROFILES
 $\alpha = 0^\circ$ $V = 1.98$ FT/SEC.
 HORI. DISTANCE IN INCHES
 VERT. DISTANCE IN CENTIMETERS
 C. E. JONES, JR.
 W. H. BROOKS, JR.





APPENDIX D
LITERATURE CITATIONS

PLATE 10
PLATE 10

LITERATURE CITATIONS

1. Daily, J. W., "Cavitation Characteristics and Infinite Aspect Ratio Characteristics of a Hydrofoil Section". ASME May 1948.
2. Ausman, J. S. "Experimental Investigation of the Influence of Submergence depth Upon the Wave-Making Resistance of a Hydrofoil." Thesis conducted at University of California 1950.
3. Scarborough, J. B., "Numerical Mathematical Analysis", Johns Hopkins Press. Pages 443-445.
4. Lamb, H., "Hydrodynamics" (Sixth Edition), Dover Publications. Pages 402, 404-415.
5. "On Waves" British Association Report 1844. Page 459.

REFERENCES

1. Bailey, J. W., "Development of the California Raisin Industry and Initial Report on the Raisin Industry of the State of California," 1924.
2. Bailey, J. W., "Development of the Raisin Industry of the State of California," 1924.
3. Bailey, J. W., "Development of the Raisin Industry of the State of California," 1924.
4. Bailey, J. W., "Development of the Raisin Industry of the State of California," 1924.
5. Bailey, J. W., "Development of the Raisin Industry of the State of California," 1924.

JUL 2
JL 2260
17 NOV 72

BINDERY
9365
22002

20521

Thesis
J69

Jones

An analysis of surface
waves generated by a sub-
merged hydrofoil.

★
JL 2260
17 NOV 72

BINDERY
9365
22002

1

Thesis
J69

Jones

An analysis of surface waves gen-
erated by a submerged hydrofoil.

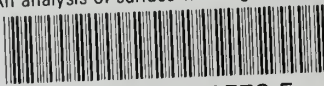
20521

Library
U. S. Naval Postgraduate School
Monterey, California



thes.J69

An analysis of surface waves generated b



3 2768 002 10578 5
DUDLEY KNOX LIBRARY